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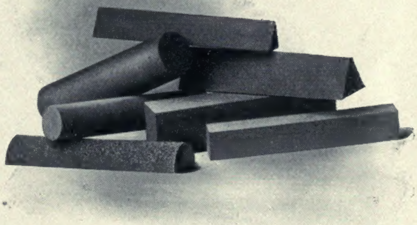

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A PRACTICAL MANUAL

FOR THE USE OF

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AND PRACTICAL MEN

BY

D. DE VRIES

AUTHOR OF "THE CALCULATION OF CHANGE WHEELS"

WITH 536 ILLUSTRATIONS

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PREFACE.

It is an indisputable fact that with the beginning of the present century the manufacture of machinery has already attained a high state of development and taking into consideration the progress which it has made in the last decade and is still making, it must be admitted by everyone, who is in anyway acquainted with any branch of the metal-working industry, that the final stage of this development is very far from being reached, but, at the present time, it may be considered as being in a very flourishing condition whilst its forces are still developing.

In speaking of metal-working, we do not refer to the working of the precious metals, the usefulness of which, except as a medium of barter, is far inferior to that of the common metals.

It is just the baser metals that become valuable by being fashioned into useful objects by the hand of the workman assisted by machines of more or less modern construction.

We say this intentionally, as nowadays the complaint is so often heard that owing to the general application of machinery, the skill of the workman is gradually becoming a thing of the past; and it cannot be gainsaid that half a century ago greater skill was often required of the workman's hand even in the metal-working industry, than is the case in the days in which we are now living.

But we would ask: Has the metal-worker's trade deteriorated on this account? Certainly not. The development which has arisen of late years in this special branch of industry has simply made other demands on the workman than was the case half a century ago, and we should not be true children of our age, if we did not strive to live up to these new requirements, and do all in our power to adapt our technical knowledge to these newer methods.

To achieve this, it is absolutely imperative that the machines required for manufacturing purposes should be known and their rational application thoroughly understood.

The purpose of the present work is to make the milling machine in its various forms more generally known, together with the tools used in connection therewith, to familiarize the reader with the manner of working on the milling machine and so make the milling machine better known and appreciated.

It is equally important that not only the owner but also the workman should be thoroughly familiar with the milling machine, should have a clear insight into this type of machine with the use of which one may at any time be entrusted; that one should be able to do with the machine everything that can be done on it, and bring to the highest point not only the productiveness, but also the quality of the work to be performed.

It is my earnest desire that this work may be of some assistance in the promotion of industry.

In conclusion, I desire to express my sincere thanks to the many home and foreign manufacturers who have so kindly provided me with the necessary information, drawings and illustrations.

D. DE VRIES.

CHAPTER I.

GENERAL REVIEW.

The Milling machine in comparison with the Lathe, the Planing and the Shaping machine.

As a result of the rapid development which the manufacture of machinery has undergone during the last decade the question of *the most advantageous manner of working* has come to the front as a factor of the first importance.

This is only natural seeing that those who are able to manufacture under more advantageous conditions than others, owing to a cheaper rate of production, are not only enabled to greatly extend their business, but, as a result of their increased profits, are also able to replace their old machines by those of the most up-to-date construction, thus assuring a still cheaper rate of cost.

The question as to the most advantageous manner of working, — *metal*working being, of course, understood both here and subsequently, — is one which is, however, not so easy to answer.

Each particular machine, each tool, each manner of working has its own peculiar advantages and disadvantages which come into prominence alternately in connection with the different pieces to be worked.

Moreover, exceptional circumstances are always occuring which it is impossible to avoid and which tend to render a correct decision still more difficult. To take a single instance — the power absorbed by a machine, the cost of tools, their durability as also that of the machine itself, besides a large number of other, smaller factors have to be taken into account when answering the question of economical manufacture.

Even the question of conservatism is one which may by no means be lightly treated.

Old shoes are so much more comfortable than new ones. Thus, each individual, each group of persons in the sphere of human activity to which they belong — in short, each nation has conservative tendencies.

We do not here refer to that conservatism which considers everything bad as a matter of course which is done in a different manner to that to which it has so far been accustomed.

Such conservatives cannot be converted, they must simply become extinct, their places being taken by a younger generation, amongst whom, doubtless, will be found the conservatives of their own time.

We are thinking here more especially of that conservatism from which the most properous man can never free himself.

Does not this explain to a great extent the cause of the enormous development of technical knowledge in the United States?

England, which has so far been to the front in technical matters, is now behind America with machine tools because she has had to struggle to free herself from the trammels of older methods, whilst America, on the other hand, which had scarcely any technical knowledge, was free to expand in this territory, untrammelled by conservative instincts.

The question as to which are the most advantageous methods of machine manufacture is thus one of primary importance for all who are in any way connected with this industry.

The answer thereto depends upon:

The chucking of the work on a particular machine.

The operations which can be performed without the necessity of rechucking.

The time needed for the operations.

The power required.

The quality of the work.

The cost of the cutting-tools, (lathe-tools, planing-tools, slotting-tools, drills, milling-cutters, etc.).

If, until comparatively recently, a comparison between the planing- and shaping-machine on the one side and the milling-machine on the other, resulted to the disadvantage of the latter, at the present time the milling-machine is even proving a keen rival to the lathe.

In ordinary machine tools, the cutting tools invariably work with a small cutting-edge, whereas with the movement of the cutting tool or the workpiece in a straight line — as is always the case with planers and shapers, — a certain part of the time required for the operation is invariably lost in useless return.

If we fix the speed for the forward movement per unit of time at 100 and that for the return at 150, the latter will cause a loss of time of 40 percent.

Seeing that the machine is working all this time, the loss of energy will consequently amount to the same percentage.

The return movement of the machine is, it is true, non-effective, but the increased speed will at least absorb the power required for cutting the material during the forward movement.

By changing the straight motion into a rotary one as is the case, with the milling machine this loss of power and time has been entirely done away with.

The only part of the milling machine with which the cutter is connected is the spindle and it is not very difficult to arrange this at any desired position as regards the work-piece, or, vice versa, to set the work-piece at any desired position as regards the cutter, so that different surfaces can be machined without rechucking. Furthermore, whilst the forms which can be machined on a planer or shaper are extremely limited, with the milling machine, on the other hand, the work which can be done, especially in conjunction with the application of copying and profiling work is practically limitless.

As regards the durability of the milling cutter no other tool can compare with this tool.

The fundamental principle of the milling cutter as a rotary cutter places it at a far greater advantage in comparison to any other cutting tool.

Whilst all other cutting tools are at work without intermission all the time they are cutting and are consequently affected by the heat generated, the milling cutter under the same circumstances, experiences a constant change of cutting edge, so that the heat generated is dissipated, whilst there is this further advantage, that owing to the larger number of working cutting edges, each tooth of a milling cutter has only a portion of the work to do.

In almost inseparable connection herewith is the quality of the finished work, so that when handled skilfully the milling machine will dispense with a great deal of manual labour.

For a considerable time the milling cutter was looked upon, as indeed it was, a very expensive tool.

The reason of this was that the construction of the milling cutter was imperfect. For a long time milling cutters were pitched too finely, mostly filed by hand, or if milled, required subsequent finishing.

It must further not be forgotten that at that time milling cutters were sharpened before being hardened, owing to the lack of the grinding wheel and that there were very few who were capable of hardening a milling cutter.

A milling cutter that had become dull had to be softened and treated all over again, whilst there was always the risk of its spoiling. For this reason milling cutters were used as long as there was any possibility of cutting, used even when they had become very dull, a circumstance which did not fail to leave its effects on the quality of the work.

This state of things has been rendered wholly different by the present-day construction of the milling cutter.

The finely pitched milling cutters have given place to the coarse pitched cutter, the milling cutter itself now being entirely produced by machinery.

Only after being hardened is the milling cutter sharpened on the grinding machine which has been invented for the purpose, whilst repeated regrinding is also possible.

As a natural result the character of the milling machine has also changed from being a special machine tool to one of general use, — to a "universal tool", and the way has been prepared for a general expansion and a continuous improvement and perfecting of the milling machine.

Before bringing this brief resumé to a close, just a few words which are applicable to so many workmen.

It is a well known fact that a large number of working men regard the milling machine with anything but a friendly eye, treat it very suspiciously and by no means exert their best endeavours to cause the milling machine to assume its rightful place, simply and solely because it works so profitably that it will supersede the manual work of their fellow-workmen. Just as if cheaper production will not lead to an increased output!

Do you not realize that the newer methods of working must and will make headway; that if you will not do it, others, more progressive than you, will, for the purpose of eventually handicapping you who have remained behind?

By you, we mean not only you personally, but the works in which you are employed, your country and your nation: for the expansion and progress of all branches of industry are most intimately bound up and associated with the prosperity of the whole nation at large.

PART I.

THE MILLING CUTTER.

CHAPTER II.

The development of the Milling Cutter.

The relative position of the milling cutter to the milling machine may be expressed by the inverse proportion which other machine tools bear to the cutting tools belonging to them.

Machine tools, such as the lathe, planer, shaper, drill, etc. have undergone a process of development entirely independent to that of their cutting tools, and only after they had been made equal to the higher demands imposed upon them, were the same demands made upon the requisite tools.

With the milling machine, on the other hand, just the opposite has been the case.

In proportion as the milling cutter proved to be a cutting tool of such supreme excellence for metalworking, the milling machine adapted itself to this higher degree of development, so that the milling machine of recent years is the result, and not the cause of the development of the milling cutter.

Although it cannot yet be said that the milling machine has been generally adopted in this country and its general use leaves very much to be desired, it is, however, some 70 years ago since the milling cutter was first brought into use; according to report, the instrument-maker Joseph Bramah, of St. Giles, London, had, even prior to the beginning of the 19th century, employed milling cutters in his workshop.

Notwithstanding the fact that about 1830 and for several decades subsequently, the milling cutter began to be employed, it still occupied a very modest place in the metalworking industry, being only made use of under quite exceptional circumstances, whilst the work which it turned out was regarded as decidedly expensive.

The cause of this was to be found in the erroneous principles on which the first makers of the milling cutters had set to work, as a consequence of which the milling cutter had been constructed with a large number of extremely fine teeth.

The reason which led to the construction of such milling cutters was the idea that the greater the number of teeth on a milling cutter, the less the strain imposed upon each tooth during that portion of the revolution in which that tooth was actually at work.

Considered alone, this would appear to have been quite correct, but owing to their number, the pitch was very fine and the teeth very shallow, with the consequent result that crowding and choking soon occured, so that a number of teeth were rendered useless and the work produced of inferior quality.

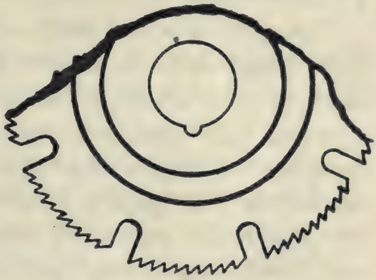


Fig. 1.
Early milling cutter with openings for chips.

Fig. 1, in which there are openings between every 10 or 12 teeth to allow of the chips escaping, clearly shows that this defect was not passed over unnoticed. The possibility of cracking with the hardening was, however, greatly increased by these openings.

Moreover, the depth of the cut was dependent on the depth of the tooth, and although theoretically the depth of the tooth may be taken as the maximum depth to be cut, in practice not more than 0.7 of the depth of the tooth can be reckoned.

The cutting depth was consequently very limited.

There was furthermore a reason for not making the teeth, especially of profiling cutters, too deep and also of not too coarse a pitch since the teeth mostly had to be resharpened with the file.

Furthermore, the grinding machine had not yet been introduced so that the milling cutter had to be sharpened before being hardened, so that a hardened cutter with really sharp teeth was practically an impossibility, the sharp edges suffering considerably in the fire. Now, a fine pitched cutter will still cut when a coarse pitched cutter has already ceased cutting, so that, viewed from this point, the preference was still somewhat in favour of a cutter with a fine pitch.

Owing to the fact that a milling cutter, which had become dull required to be treated all over again whilst these was also a great risk of its cracking during the hardening process, the cutter was used as long as possible, so long in fact, that it began to turn out bad work, and consequently, as far as the quality of the work was concerned, it could no longer be accounted one of the best of cutting tools and was simply employed where manual labour was very expensive.

For these reasons the milling cutter made practically no advancement for a number of years, but notwithstanding the serious defects with which the milling cutter was hampered, it came slowly but surely into more general use.

It was chiefly in the manufacture of rifles, sewing machines and similar articles produced in large quantities, that the milling cutter, although expensive, was employed for the purpose of turning out cheaper work.

In these factories certain workmen were continuously occupied with the making and hardening of milling cutters and were thus in a position so to improve the milling cutter (and in direct connection therewith, the quality of the work which it turned out), so that the milling machine was able to take the place of a considerable amount of manual labour and it thus became a really indispensable factor in such manufacture. From that time onward, the milling cutter came more and more into general use in these and similar factories and was constructed in every possible shape and form.

It is curious to note that the formed cutter in its most complex form was the precursor of the plain milling cutter, and as soon as the latter was constructed in the right manner under these new methods, the formed cutter found general application.

It was in the United States that Messrs. Brown & Sharpe first manufactured milling cutters of a new type, the coarse pitched cutter, and as a natural result with much deeper teeth, thus making it possible to take a deeper cut, so that these cutters could be used for work-pieces of considerably larger dimensions.

Almost at the same time this firm first introduced the emery wheel for sharpening cutters after hardening.

This new type of cutter had important advantages:

1st So as has already been said, more metal could be removed.

2nd The cutter could not only be sharpened after hardening, but a cutter which had become dull could be reground in its hardened state, thus prolonging its usefulness tenfold. It was now no longer necessary to let the cutter get absolutely dull in order to use it as long as possible; it could now be kept sharp at comparatively little cost and, consequently:

3rd The quality of the work turned out was considerably improved.

This revolution in the science of milling cutters took place in the States about the year 1870, and became generally known in Europe during the Exhibition in Vienna in 1873.

However strange it may seem now that this type of cutter has been universally adopted and its undeniable superiority to the old European type is no longer doubted, it was regarded very distrustfully and European experts were very reserved in expressing their judgment. Even we ourselves can remember that after the coarse pitched cutter had been introduced, certain very clever and otherwise shrewd experts and engineers regarded the new cutting tool with many a shake of the head.

When however, the Worlds Exhibition at Philadelphia in 1876, exhibited to European experts a universal and many-sided application of the coarse pitched milling cutter which exceeded even the most sanguine expectations, the most far-seeing engineers were then convinced of the immense advantages which the application of the new type opened up for the metalworking industry, and from that time onwards the American type advanced, slowly at first, but later on with rapid strides, so that, at the present time, it is quite an exception to come across a fine pitched cutter.

The teeth were formerly ground on the back-side of the milling cutter. Now, it was practically impossible to regrind a formed cutter on the back-side in such a way that the cutter would not lose more or less of its original form after regrinding, a fault, which for profile work at any rate could not be overlooked.

All sorts of ingenious devices for grinding were experimented with in order to avoid this defect, but without success, so that for curvilineal surfaces the fine pitched cutter still remained for some time in general use, until, the „backing off" of the cutters was introduced, again by Mess^{rs} Brown & Sharpe, and the frontside of the cutter could be reground, thus ensuring a perfect similarity of the milling work both before and after grinding.

At the same time another excellent improvement was obtained, viz: that the teeth of plain cutters were no longer milled straight but in such a way that each tooth formed a spiral line, whilst some years later the „backed off" cutter underwent a still further improvement in certain forms of cutters, by its being backed off sideways.

CHAPTER III.

Denomination of Cutters.

a. CLASSIFICATION.

Under the title of "Cutter" are included all those cutting tools possessing several cutting edges all working in the same circumference or on one and the same surface. In the following description one single exception will shortly be met with in the separate types referred to under group I. The outside lines of a cutter are straight, broken or curved; if straight, the outside lines form together a cylinder or cone; if broken, then the lines lie altogether in a common rotating body.

A further general characteristic is that all the teeth have the same form and are placed equidistant from each other in a circle. In this connection, there are, however, a few exceptions.

For what is understood by the word "cutter", it is not at all necessary that the teeth should form one whole with the body, they can equally well consist of separate parts, not only that they are then united with the body so as to form an undivided whole, or are exchangeable, but also from the point of view that they can differ as to the material from which they are made.

The cutting parts are accordingly distinguished as teeth and blades. Teeth form one whole with the body of the cutter but blades do not.

Practically without exception a rotary movement is imparted to the cutting edges of a cutter round a common centre, which in connection with an uninterrupted straight, curved or relative motion from cutter or work-piece, enables the cutter to perform its work uninterruptedly.

The cutting edges thus traverse a certain course which takes the shape of a closed, curved or straight line.

Each cutting edge of the cutter does not work continuously but at intervals, at the most during half the time taken up by one revolution; in this respect it is similar to the shaping and planing tool but differs from the lathe tool and the drill.

As the cutter can be used for a variety of operations in the broadest sense of the word, it is accordingly constructed in a variety of forms, cylindrical as well as conical, as a rotating body with curved lines, composed of two or more of the first-named principal forms, whilst the different lines of its cutting edges are also very divergent.

For the purpose of classifying the different types it is scarcely possible to take the form of the cutter or of its teeth as a basis, a much simpler grouping being obtained by separating them according to the manner in which the cutter works.

Taking this as the basis, the different types can be arranged in groups as follows:

Group I. Cutters composed of blades which are either ex- or interchangeable.

Group II. End-mills. To this group belong all cutters used for working surfaces, the teeth or blades of which run in a radial form.

Group III. Shell-mills. This group includes all cutters, the teeth of which lie on the circumference of a rotatory body, the cutting edges together forming such a body circumscribed by straight lines.

Group IV. Shell-end-mills. A combination of the types referred to in groups II and III.

Group V. Formed cutters. In this group the backing-off of the cutter is principally employed.

Group VI. Composite cutters. In this group are usually reckoned cutters composed of two or more of the foregoing types.

b. GROUP I. CUTTERS COMPOSED OF BLADES.

This group may be subdivided into:

1st Cutters, the blades of which are interchangeable.

2nd Cutters, the blades of which form one complete whole with the body.

a. Fig. 2 represents the simplest form of type 1, which, as it works with only one cutting edge and can remain uninterruptedly at work, may be considered as a deviation from what is ordinarily understood by a "cutter" and displays a great resemblance to the lathe tool.

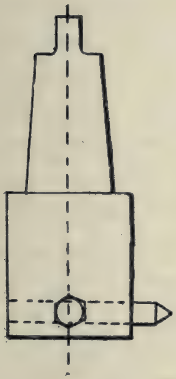


Fig. 2.
Cutter with single-edged tool.

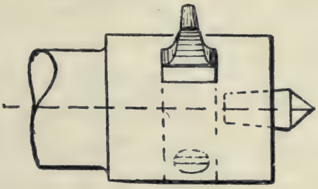


Fig. 3.

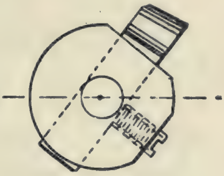


Fig. 4.

Cutter with single-edged tool.

It is mostly used for large borings and in holes which are not a closed circle.

b. Figs. 3 and 4 also show a cutter with one blade which is however distinctly different

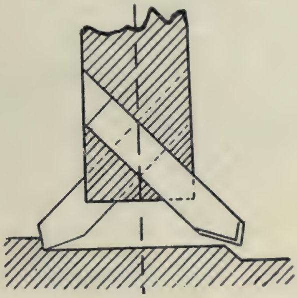


Fig. 5.
Cutter with two tools.

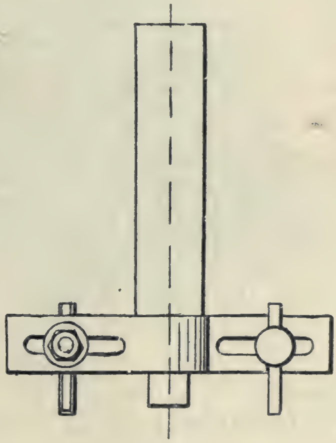
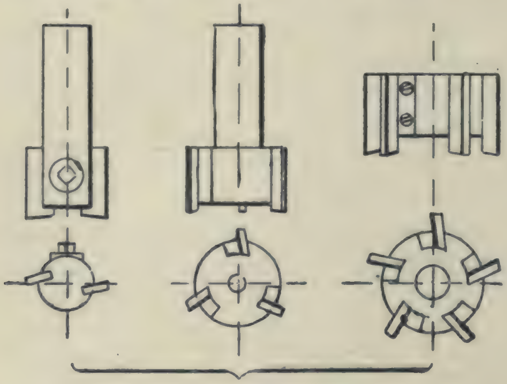


Fig. 6.
Mill for cutting out sheaves.

to that shown in fig. 2, in that it cannot continue uninterruptedly at work. It is but seldom used and then only in the manufacture of bronze or wooden gear wheels.

c. Fig. 5. Shows a face mill with two inserted teeth which can be used either for face milling or for milling holes or segments. When used as face cutter its work is not uninterrupted, but when used for milling a complete circumference it can work continuously, in which case it has an advantage over that referred to under *a.* in that by giving both tools a difference in height of $^1/_8''$ a cut of double depth can be taken.



Figs. 7—9.
Cutters with two, three and five inserted teeth.

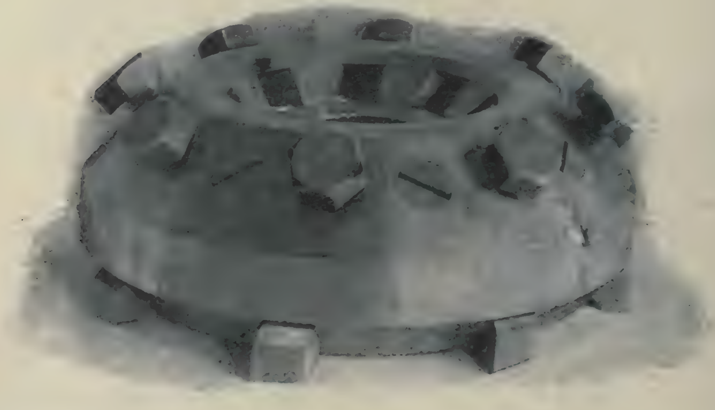


Fig. 10. Inserted tooth cutter.

d. Fig. 6. Represents a mill with two teeth. It is principally used for cutting holes and manholes in boiler shells, etc.

e. Figs. 7—9. Cutters with two, three and five inserted teeth which are used for milling keyways, for milling oblong holes and for border surfacing the width of which does not exceed the diameter of the mill.

f. Figs. 10 and 11. These are termed inserted tooth cutters, and are employed for milling large, rough surfaces, such as the joints of split flywheels or rope pulleys, joints of large machine parts, etc.

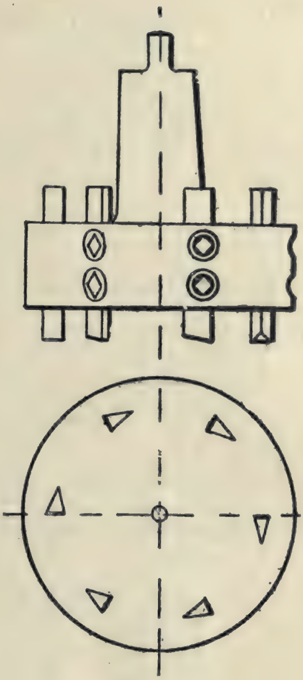


Fig. 11.
Inserted tooth cutter.

g. Fig. 12. Represents an inserted tooth mill which is employed for grooves and surface milling.

h. Fig. 13. This mill differs from what is generally understood by a "cutter" in so far that the form of each of the teeth varies alternately. A large quantity of material can be removed with this mill. The working method is similar to that of fig.12. The cutter shown in fig. 12 will be chiefly used when a groove has already been milled in the material; the cutter illustrated in fig.13, being employed when a deep, broad groove has to be milled from the solid material.

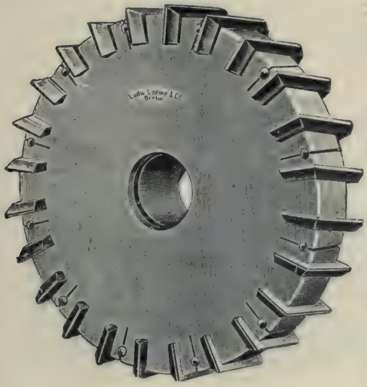


Fig. 12.
Inserted tooth cutter.

The mills classified under 2 are employed only for milling rough surfaces.

Fig. 14 illustrates such a miller.

In the foregoing, blade and tooth millers have been dealt with as an independent group, without taking into consideration their manner of working; Considered with reference to this, they would have to be divided up with the various other groups. Taken however together as an independent group, a much better idea is gained of this sort of millers.

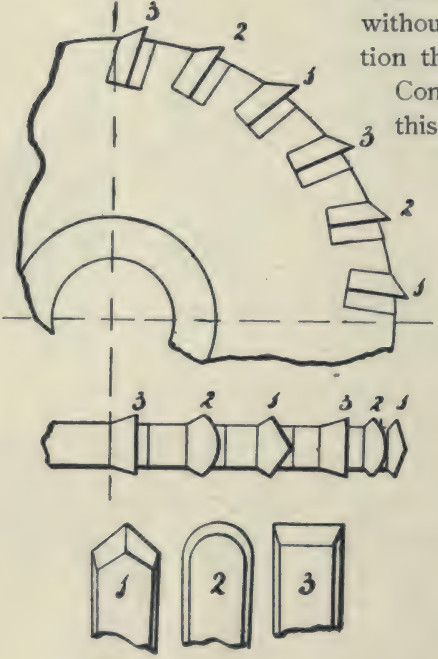


Fig. 18.
Inserted tooth cutter with cutters of different form.

c. GROUP II.
END MILLS.

This is a type that, owing to its limited use, is seldom employed.

a. Fig. 15. Shows this type in its original but bad construction, which has been rather more used of late in this particular form.

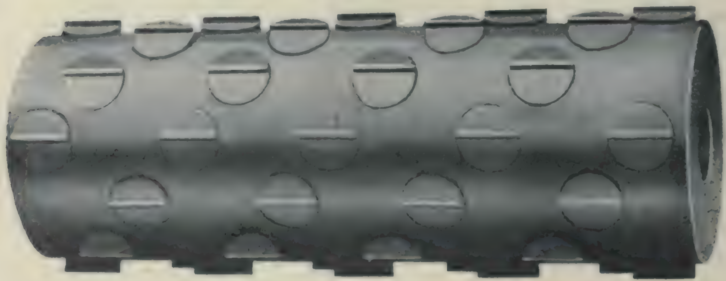


Fig. 14. Plain miller.

b. A cutter of similar form is illustrated in figs. 16 and 17.

The proportion of the width of the teeth to the diameter of this mill is greater than in that illustrated in fig. 15, so that its use is different. Fig. 17 shows the manner in which it works.

c. An end mill as illustrated in fig. 18, which is used for milling pinions, can, under certain conditions, be employed to good account; for example, in milling pinions, the outside diameter of which is either equal to or smaller than that of the shaft of which such pinion forms a part; it is also employed on milling machines with vertical spindle only as also for milling spiral gear wheels.

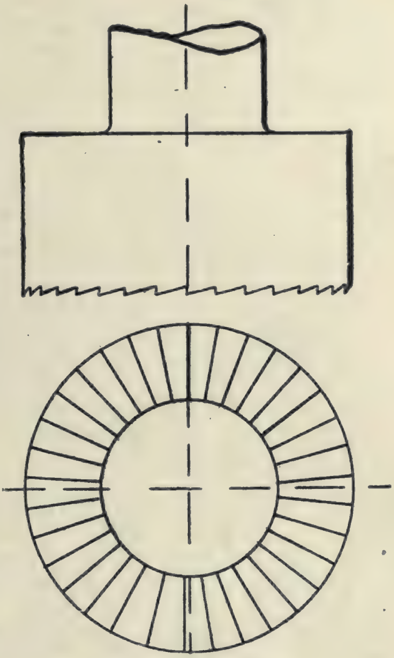


Fig. 15. End mill.

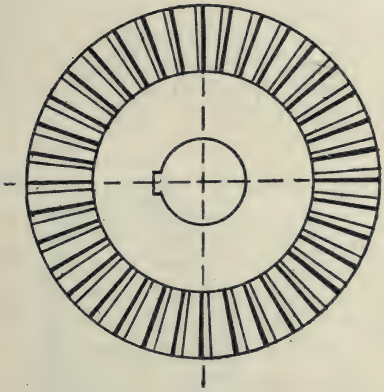


Fig. 16. End mill.

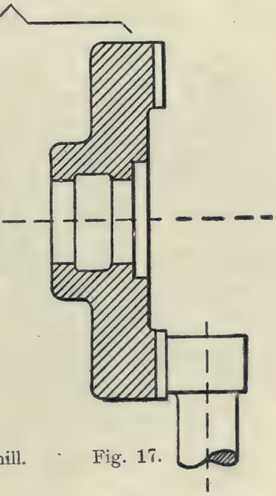


Fig. 17.

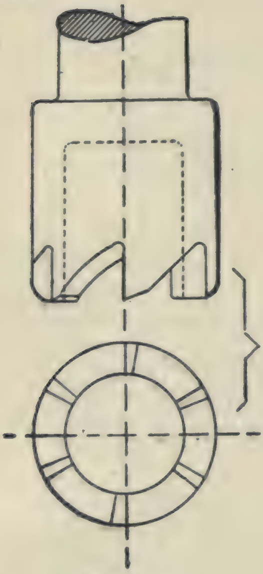


Fig. 19-20.
Hollow mill.

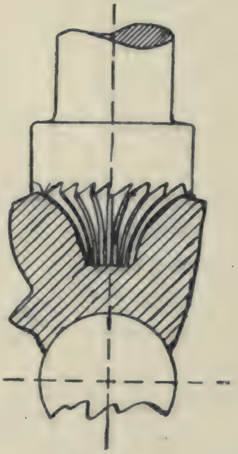


Fig. 18.
End mill for milling pinions.

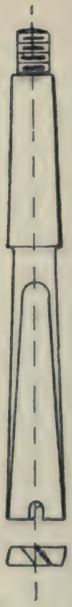


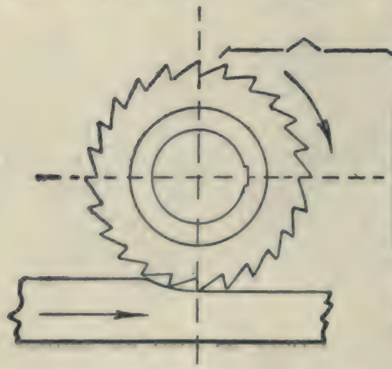
Fig. 21.
Double edged cutter.

d. Figs. 19 and 20 represent a mill for the milling of round pins.

e. Fig. 21 is a miller extensively used for milling narrow faces, keyways, oblong holes etc.

d. GROUP III. SHELL MILLS.

This group may be directly divided into two constructions which are very easily distinguished the one from the other.



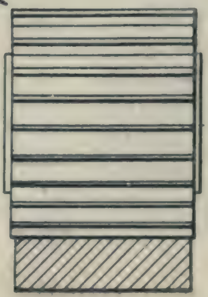


Fig. 22. Shell mill. Fig. 23.

1st Millers, in which the cutting edge of the teeth runs parallel to the centerline of the miller.

2nd Millers, in which a certain number of teeth bisect a line drawn through the external diameter parallel with the core of the mill, i. e., where the cutting edge of one tooth is a spiral.

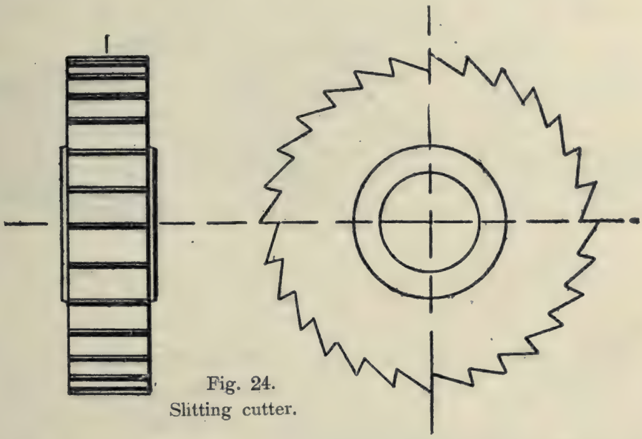


Fig. 24.
Slitting cutter.

a. The simplest type of the millers referred to under 1 is shown in figs. 22, 23 and 24.

The cutter with coarse pitch was first introduced in this form.

The mill shown in figs. 22 and 23 is principally used for surface milling, that, illustrated in fig. 24 for milling keyways etc.

b. The screw slotting cutter fig. 25 is very similar to the foregoing, only being considerably thinner. The thickness depends upon the diameter of the screw head or the width of the slot which it must slit. It is even made up to a thickness of $^1/_{64}''$.

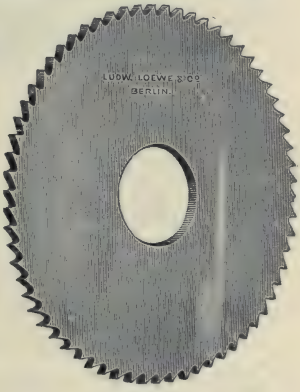


Fig. 25.
Screw slotting cutter.

c. Conical millers as represented in figs. 26—28 are chiefly used for milling sloping faces.

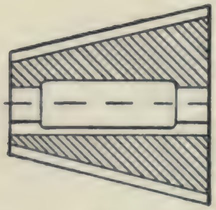


Fig. 26.

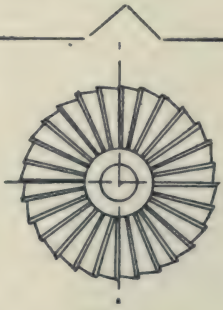


Fig. 27.
Conical mill.

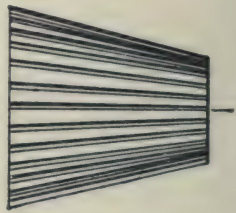


Fig. 28.

d. Fig. 29 shows the type of mill referred to under 2 most commonly in use. It is used for the same purposes as the miller depicted in fig. 22—23.

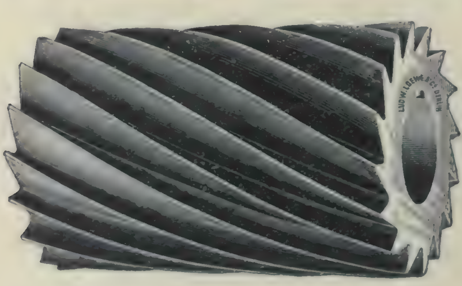


Fig. 29.
Shell mill with spiral teeth.

Owing to the spiral form of the teeth, a greater number are engaged on the work at the same time on each line of the surface being milled parallel to the core of the mill. The irregular working of the mill over rough surfaces is consequently diminished as before one tooth has left the cutting surface, other teeth have begun to cut, thus ensuring smooth cutting.

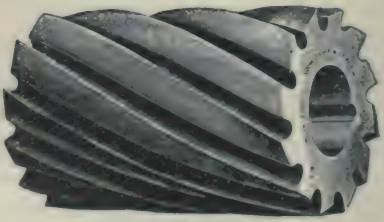


Fig. 30.
Shell mill with backed-off spiral teeth.

Another advantage in favour of the spiral mill is that it very seldom happens that the tooth is cutting over its full length. The cutting charge is generally divided over a certain number of teeth, whilst a further advantage is that the tooth, instead of taking up the cut suddenly over the entire length of the cutting surface, gradually advances to its maximum cutting length, thus greatly reducing the danger of teethbreaking.

e. Fig. 30 illustrates the same miller as fig. 29 with the difference that the teeth are much stronger to admit of milling tougher material.

e. GROUP IV. SHELL END MILLS.

This group may be divided into the following principal types:

1st Side or straddle milling cutters with straight teeth on both sides and edges.
2nd Side or straddle milling cutters with spiral teeth.
3rd Angular cutters.

a. Fig. 31 is the simplest type of the cutters referred to under 1. It is used for milling right-angled surfaces.

b. Fig. 32 is used for cutting T slots.

c. Figs. 33 and 34 serve for milling triangal grooves and are much used for milling the teeth of small cutters.

d. Angle cutters are illustrated in figs. 35—37. These cutters are made with different angles according to the nature of the work to be performed.

e. Fig. 38. Shows a cutter of the type referred to under 2. It is very much used in different diameters and lengths.

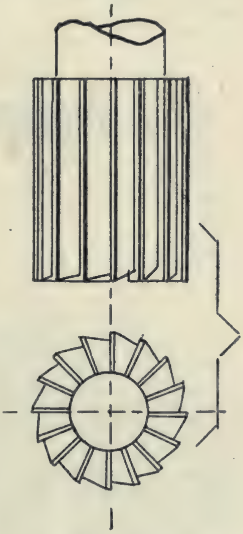


Fig. 31.
Shell-end-mill.

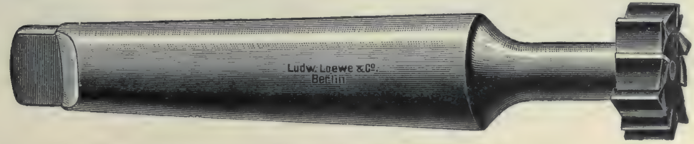
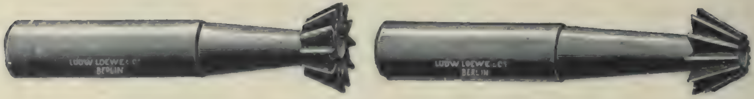


Fig. 32. T slot cutter.



Figs. 33 and 34.
Small angular cutters.

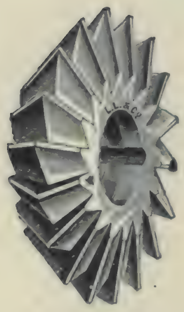


Fig. 35.
Angular cutter.

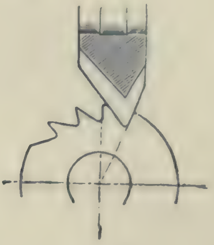


Fig. 36.

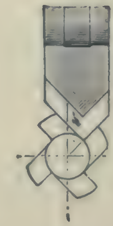


Fig. 37.

Angular cutters.

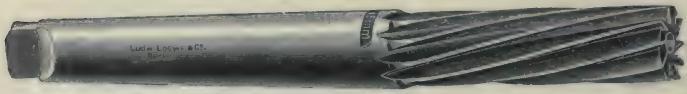


Fig. 38. End mill with spiral teeth.

f. Side milling cutter (fig. 39), are used for widening slots, milling keyways and used in pairs for sizing nuts, bolt heads, etc. and are then called "straddle mills". They have teeth upon both sides and edges. (fig. 40).

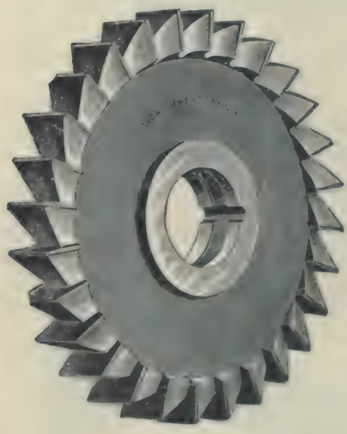


Fig. 39.
Side milling cutter.

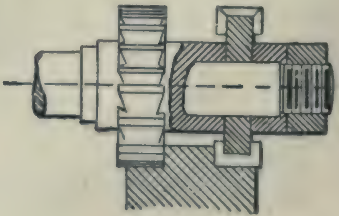


Fig. 40.
Straddle mill.

g. Figs. 41—42. These cutters are made in two parts and can be adjusted easely for maintaining a standard width of slot.

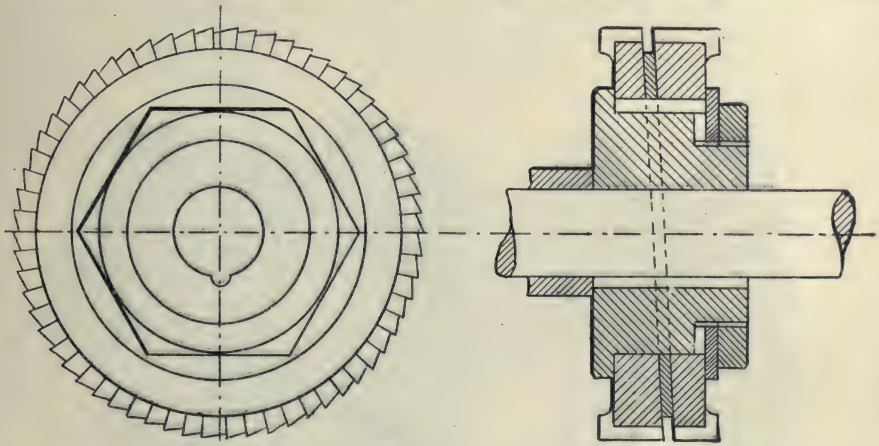


Fig. 41. Interlocking side milling cutter. Fig. 42.

f. GROUP V. FORMED CUTTERS.

As has already been stated in Chapter II, formed milling cutters were the first to be used. Latterly the old European type has been almost entirely superceded by the backed-off milling cutter, which latter consists of such a variety of

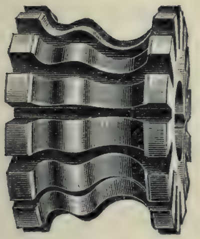


Fig. 43.
Formed cutter for
milling ledges.

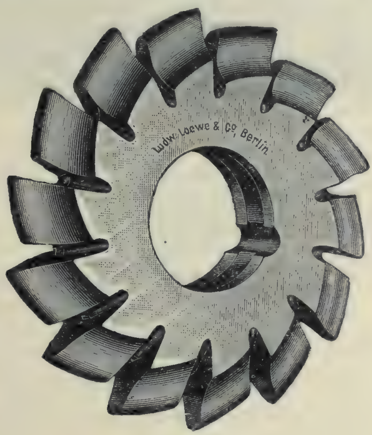


Fig. 44.
Gear cutter.

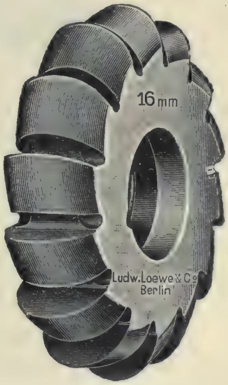


Fig. 45.
Convex cutter.

forms and size that it is wellnigh impossible to illustrate even the principal forms.

A few of the different forms of the backed-off formed milling cutter are depicted in figs. 43—48.

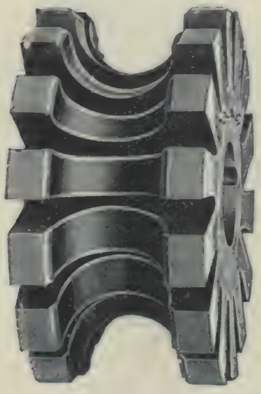


Fig. 46.
Concave cutter.

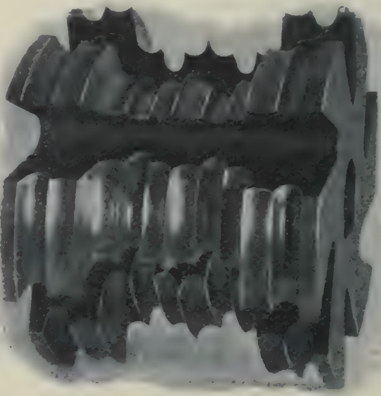


Fig. 47.
Backed-off formed cutter.

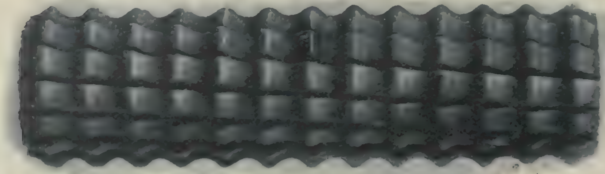


Fig. 48.
Backed-off formed cutter with spiral grooves.

g. GROUP VI. COMPOSED FORMED CUTTERS.

There is at least a limit to the width of the backed-off milling cutter. The tool with which the teeth of the cutter are backed-off, must, if the latter have an irregular form, have the same shape.

If the form of the cutter is composed of straight lines which can be traversed by the tool in a transverse direction composing will not be necessary and the cutter can be backed-off with a common lathe tool. In this case the tool can be constantly set in in a slightly transverse direction whilst the cutter or a portion of it can be backed-off by a common lathe tool. Should the form however, be such as to render this impossible, the tool will then have to be set in square on the centre line of the cutter and the whole width of the cutter worked in one cut.

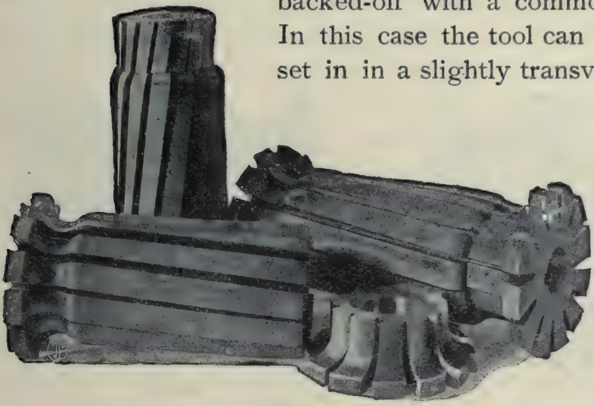


Fig. 49.
A few composed formed cutters. The foremost has been taken apart.

When, however, the formed milling cutter came more and more into general use and even the beds of lathes and the tables of horizontal and vertical milling machines were milled over their entire width by one mill in a single cut, milling cutters were required for

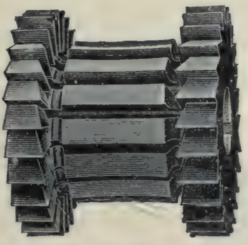


Fig. 50.

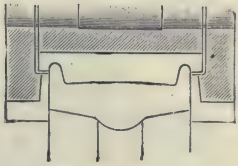


Fig. 51.
Composed backed-off cutter for milling flanged pulleys.

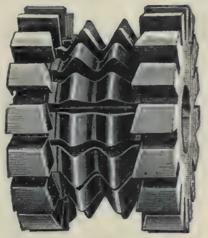


Fig. 52.

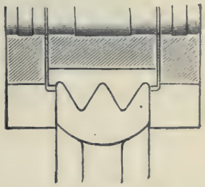


Fig. 53.
Composed backed-off cutter for milling rope pulleys.

this purpose, which in addition to their composit form, attained a length of 20 inches or more, so that such cutters could no longer be manufactured from one piece.

A number of sheaves of varying thickness are therefore made which are either first held together with suitable pins or simply kept in position by a true keyway, after which the desired form is given to the whole on the lathe, when the cutter has been turned in this form, it is dismounted and each separate sheave finished off as an ordinary backed-off cutter. Naturally, in fixing the thickness of the sheaves, the form of the cutter has to be taken into consideration.

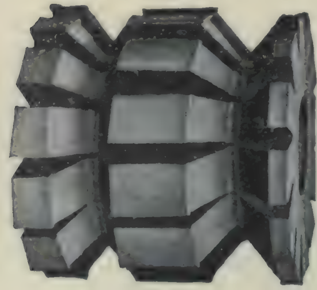


Fig. 54.
Composed backed-off cutter with irregular cutting edges.

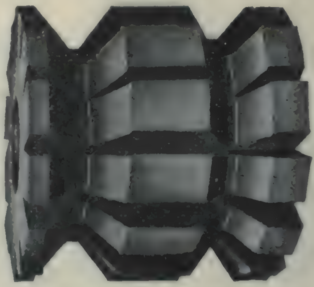


Fig. 55.
Composed backed-off cutter with irregular cutting edges, ready for grinding.

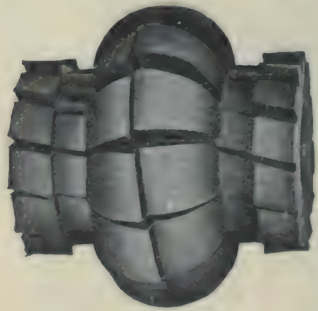


Fig. 56.
Composed formed cutter backed-off at sides and circumference.

The milling of spiral grooves is scarcely possible with a cutter such as that illustrated in fig. 54.

The cutting edge is then interrupted, as can be seen in fig. 54. The cutters are provided with two sets of keyways. The key runs in one set when the cutter is being used for milling and in the other when the cutter is ready for grinding.

The more the plane parallel to the centre line of the cutter inclines to the line rectangular to the centre line, the cutting angle at that point is consequently reduced. If the cutting edge is a line squared on the centre line, the cutting angle is then 90^0. and scrapes along the workpiece.

For small raised edges this is less important as the teeth on the circumference remove practically the whole of the material.

If, however, the raised edges are higher or lines of semicircular form as shown in fig. 56, the teeth must also be backed-off on the sides. The cutter in fig. 56 consists of 4 parts; the two outside parts being backed-off on the circumference and at the sides, and the two middle parts, the connecting surfaces of which form a spiral.

A number of sheaves of varying width are therefore made which are either first held together with suitable pins or simply kept in position by a true keyway, after which the desired form is given to the whole on the lathe; when the cutter has been turned in this form, it is dismounted and each separate sheave finished off as an ordinary backed-off cutter. Naturally, in fixing the thickness of the sheaves, the form of the cutter has to be taken into consideration. The milling of spiral grooves is scarcely possible with such a cutter as that illustrated in fig. 56.

CHAPTER IV.

The working methods of the cutter.

a. THE RELATIVE POSITION OF CUTTER AND WORKPIECE.

The manner in which workpieces are treated by the cutter, the shape which can be given to a particular piece of work, do not solely depend on the form of the cutter, but also on the movement imparted either to the cutter or to the workpiece or to both together at the same time, during the rotary motion of the cutter. It is quite possible, provided the construction of the machine on which the cutter is being used permits of it, to turn out many different kinds of work, to obtain the most divergent forms and to finish off a piece of work either wholly or partially with the same cutter.

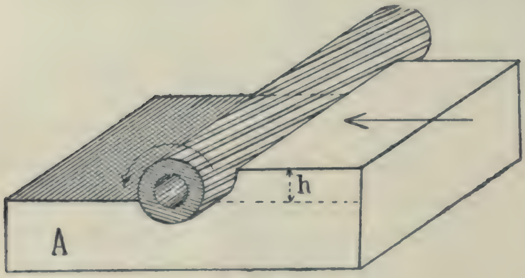


Fig. 57.
Shell-mill surfacing.

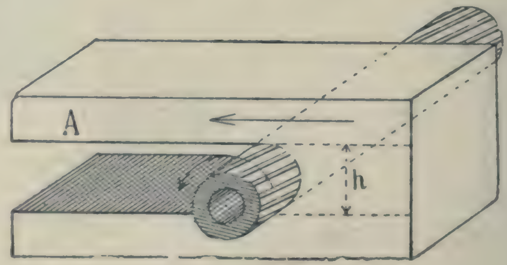


Fig. 58.
Shell-mill slitting.

Leaving the formed cutter on one side for a while, it is quite possible to carry out an illimitable number of operations with the plain milling cutter of which the principal kinds will now be dealt with successively.

In figs. 57 and 58, whilst the cutter is completing the rotary movement indicated by the arrow, a movement in a contrary direction, either to the workpiece or to the cutter, is imparted to the rotary cutting movement of the cutter. In cases as indicated in figs. 57 and 58, this horizontal movement in a straight line is almost invariably imparted to the workpiece that is fastened with bolts to the milling table or chucked. The cutter thus remains stationary, whilst the workpiece moves.

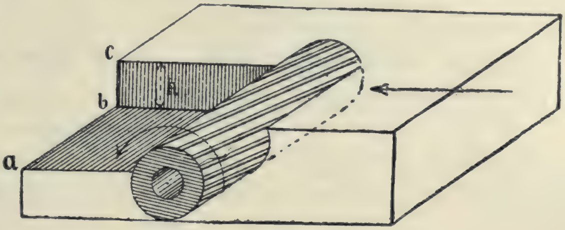


Fig. 59.
Shell-mill milling portion of a flat surface.

In figs. 57 and 58, the lenght of the cutter exceeds the width of the plane which is to be machined, and seeing that the direction of movement of the workpiece is parellel to its undersurface, either one plane or two new planes will formed parallel to either one or both planes of the workpiece. Whilst the cutter in fig. 57 is milling the upper surface, from which a certain depth h is being removed, thus reducing the thickness of the piece, the cutter in fig. 58 is working at a certain distance from the two planes, so that a slit h equal in width to the diameter of the cutter, is milled, or, if going through the whole piece, the two parts become separated.

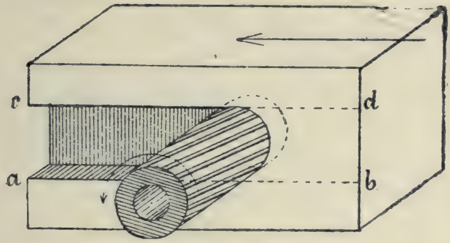


Fig. 60.
Milling a groove with a shell-mill.

The same operation is to be seen in figs. 59 and 60 as in figs. 57 and 58, with this single difference that in this case the length of the cutter, or to be more correct, that portion of its engaged in working, no longer exceeds the width of the plane, so that, as a consequence only a portion of the plane is machined and removed.

However trifling this difference in the working may be, the results are very divergent.

These four examples show in their simplest form a few of the principel operations.

Fig. 57 shows the most favourable manner of working as far as the cutter is concerned, the material being all cut away parallel to the core of the cutter, whilst the direction in which the teeth move during the time they are cutting is just the opposite to the direction in which the workpiece is moved. All the material which is cut away is directly free, so that it is impossible for the teeth to become clogged.

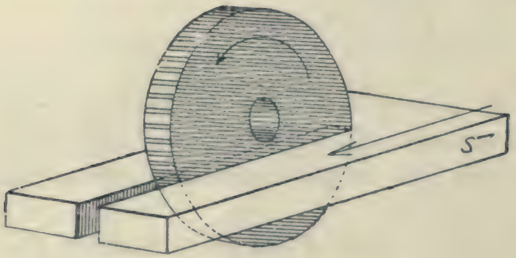


Fig. 61.
Milling a slot with a slitting cutter.

In fig. 58, the contrary movement of the teeth to the direction in which the workpiece is being moved is changed above the line drawn over the centre of the cutter parallel to the under surface into a movement in the same direction, so that the cutting of the upper half is less favourable.

In fig. 59 the cutter is milling a right angle in the workpiece, the material being cut away in the same manner as shown in fig. 57, though with this difference, that the plane *b. c.* is formed not by the *cutting away* but by the *breaking off* of the chips. Provided care is taken that the front of the cutter is concave, a fairly accurate plane can be formed in this manner. It must, however, be borne in mind, in order to get a right idea of the working of the cutter, that the plane *b. c.* is not *milled*, but formed by the *breaking* off of the chips.

Finally, in fig. 60 the working of the cutter is a combination of that shown in figs. 58 and 59, and in this way a groove is milled throughout the dotted lines, the rear plane, which is really the bottom of the groove, being formed not by milling, but by the chips continously breaking off. It must be borne in mind that we have in view here a shell mill also without teeth at the front, so that figs. 61 and 62 show this more clearly.

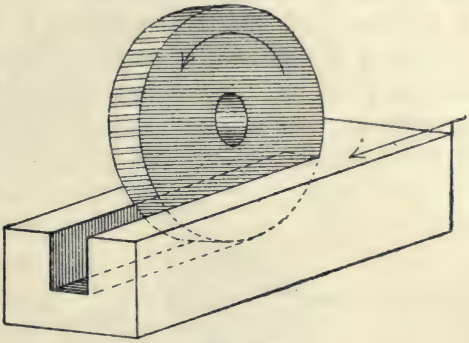


Fig. 62.
Milling a groove with a slitting cutter.

If the results obtained with the cutter in the workpieces in figs. 61 and 62 be compared with those in figs. 58 and 60, it will be found that they are precisely similar, though the manner in which the material is cut away in the former cases is totally different to that in figs. 58 and 60. At the same time it will be noticed that the centre line of the cutter is no longer perpendicular to the ground plane of the groove but runs parallel to it. If in fig. 58 a portion of the teeth of the cutter happens to work under unfavourable conditions owing to the direction of movement of the upper portion of the teeth being no longer contrary to the direction of movement of the workpiece, this is not the case in fig. 61 in which the direction of movement of all the teeth engaged on the work is contrary to the direction in which the workpiece is moved; only a

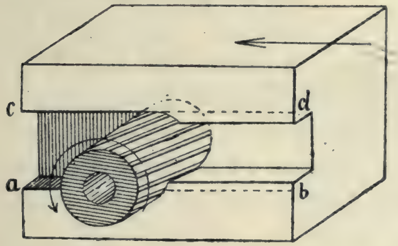


Fig. 63.
Milling a groove with a shell mill.

small portion of the total number of teeth on the cutter are engaged on the work, thus causing but a trifling heating of the cutter.

In the case of a cutter working as shown in fig. 62, this noticeable difference noticed in addition to what was pointed out above will be that whereas in fig. 60 the material is cut away on the sides along the lines *ab* and *cd*, the chips breaking off at the bottom, in fig. 62 the order of things is reversed, the material being cut away along the bottom and the chips breaking off at the sides. It practically goes without saying that as this breaking off occurs at the extremity of the teeth where the chips are formed, no point on the sides of the cutter can come beyond the width of the teeth without causing considerable friction and as a natural result heating of the cutter with other attendant results.

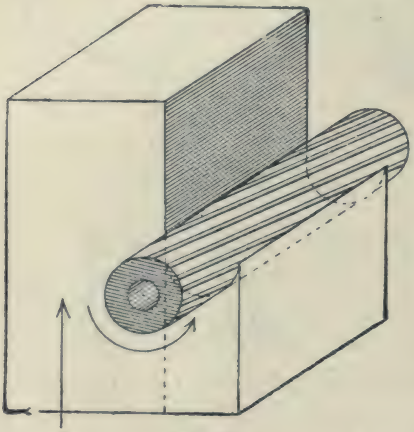


Fig. 64.
Horizontal rotating cutter with vertical feed movement.

The unfavourable results of a cutter working as shown in fig. 58 are still more clearly evident in fig. 63. In this instance the groove has already been cast in the piece. Now, the surfaces of castings are very hard, steel pieces also having a hard surface owing to the oxydation of the hot iron or steel.

If the cutter begins to work on a rough surface, as is the case in fig. 57, it will first come in contact with this hard surface which it will have to cut away, although a careful workman who is saving with his tools will prefer to remove this crust first with a file or chisel. When once the cutter has gone through the rough crust, the teeth cut the soft material from the beginning of the cut and only touch the crust at the end. This finally breaks off and the cutting edge of the teeth is saved from coming in contact with the hard surface of the workpiece.

This is the case along the line *ab* in fig. 63, but along the line *cd* the teeth of the cutter first come in contact with the hard surface, and only when they have gone through it, do they cut into the soft material.

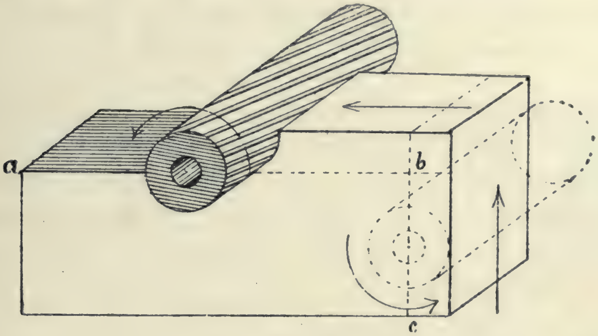


Fig. 65.
Horizontal rotating cutter with horizontal and vertical feed movement.

If a large number of grooves of the same width have to be milled, the manner of working illustrated in fig. 62 is the most commendable. To give an example of workshop practice: A certain factory has a number of keys in stock of different width and for each width there is a suitable cutter, then, after having been but a short time in use, the

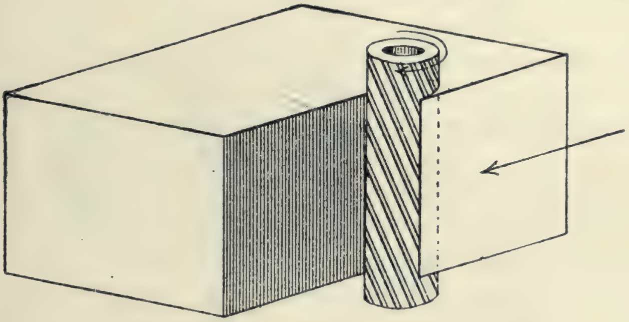


Fig. 66.
Vertical rotating miller with horizontal feed movement.

cutter, according to fig. 63, will mill a narrower groove than when first used.

On the other hand, by working as shown in fig. 62, the grooves milled will always be of precisely the same width. There is always wear; in the cases illustrated in figs. 60 and 63 the wear will have an appreciable effect on the width of the groove cut, but not in the case of figs. 61 and 62.

Moreover, narrow grooves can be milled much quicker by the manner shown in figs. 61 and 62 than by that shown in figs. 58 and 60.

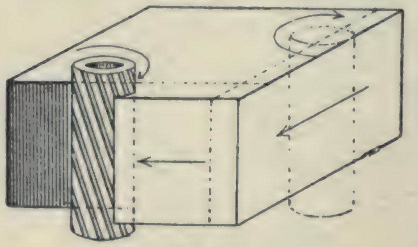


Fig. 67.
Vertical rotating miller with horizontal, longitudinal and traverse movement.

In the foregoing cases it has been presumed that the workpiece has only been moved in a horizontal direction parallel to the centre line of the cutter, so that only a horizontal plane can be formed by the teeth on the circumference of the cutter whilst the front of the cutter can only form a vertical plane; as soon however as a vertical feed is given to the workpiece, the teeth on the circumference will form vertical planes, (fig. 64), whilst by feeding in both directions, it is possible to cut two planes at right angles to one another (fig. 65). If vertical planes have to be milled with horizontal feed of the workpiece, then the cutter will have to work in a vertical direction as in fig. 66, and thus with two perpendicular movements one after the other, it will be possible to form two rectangular planes (fig. 67).

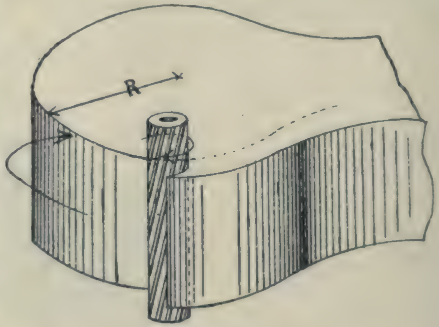


Fig. 68.
Vertical rotating cutter with rotary feed movement.

A vertical rotating cutter is almost invariably adopted whenever circular or profiled lines have to be formed, and for this reason, that not only does this permit of a better view of the workpiece, but the table or the workpiece can move much better along a horizontal than a vertical formed line.

A profiled line can be obtained in two different ways, first when the line forms a circle, the segment of a circle or a union of arches of a circle. In this case, an imaginary centre can be fixed upon for the circle or the arch which is to be cut, equivalent to the centre round which the milling table rotates. Figs. 68 and 69 give two examples of this. In fig. 68 the centre of the circle to be worked lies within the workpiece itself.

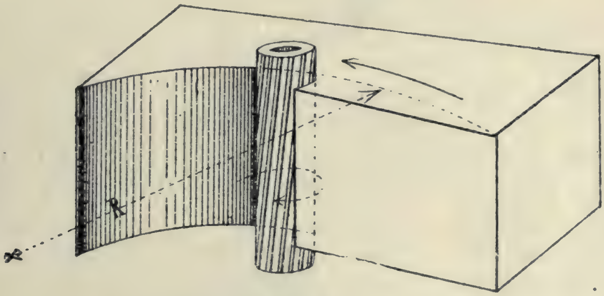


Fig. 69.
Vertical rotating cutter with rotary feed movement.

In fig. 69 on the contrary, it lies far outside.

The profile line can, however, consist of lines which form no parts of a circle, or of a large number of small arches, in which latter case it is quite possible that the trueness of the profile will be reduced, owing the various arches joining less accurately. In such cases the profile lines can be formed by a combination of two rectangular movements, the slide moving along a cam (fig. 70).

If, in addition to a longitudinal feed, a slowly rotating movement is imparted to the workpiece, this will cause spiral groves which can be formed equally as well by a cutter moving in a vertical as in a horizontal course (fig. 71).

The working of a flat faced slitting cutter rotating horizontally however hides a fault which, in the case of shallow grooves is not of such great importance, viz: that the sides of the cutter form right angles with the teeth and consequently have to force a way through a groove which is formed by two spiral lines; the groove is cut according to the width of the cutter, so that if two straight lines are drawn along the spiral lines, their width will not be as great as the width of the cutter, which will consequently work through the groove with considerable friction.

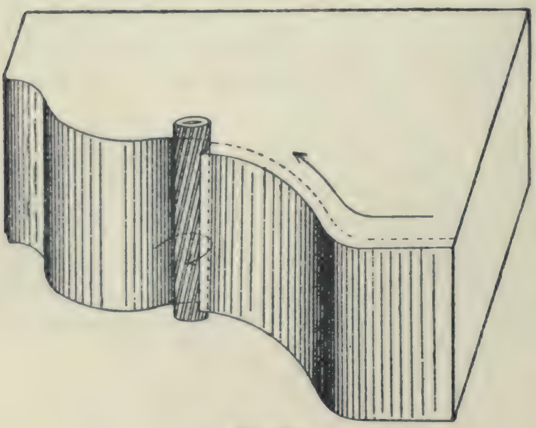


Fig. 70.
Vertical rotating cutter profiling work.

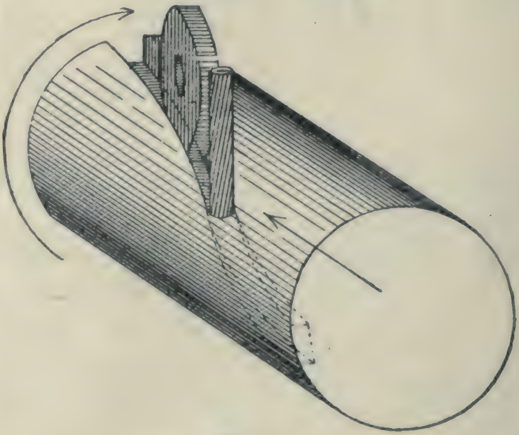


Fig. 71.
Working method of a slitting cutter and an end-mill milling a spiral groove.

If the centre line of the cutter forms any other than a right angle with the milling table on which the workpiece is placed, sloping planes will be formed (fig. 72).

If, moreover, the feed of the table is circular, conical planes will be formed (fig. 73).

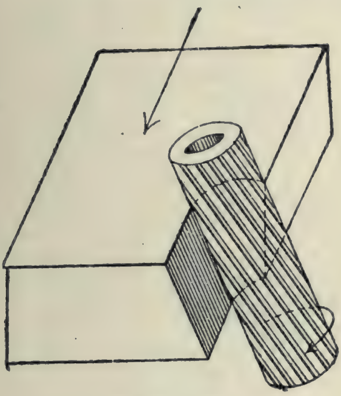


Fig. 72.
Slope plane cut with a cylindrical cutter.

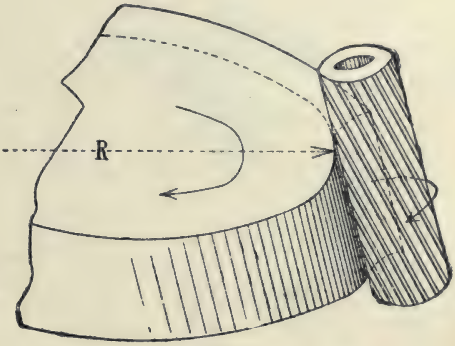


Fig. 73.
Conical plane cut with a cylindrical cutter.

Conical planes can also be obtained with a conical cutter the centre-line of which runs rectangular with the milling table (fig. 74). If, however, the spindle cannot be moved from a perpendicular or horizontal position, only one conical plane can be formed by one particular cutter. If, on the contrary, the spindle is adjustable, the use of a conical cutter, which is much more difficult to make and keep in order, becomes unnecessary and, therefore, undesirable.

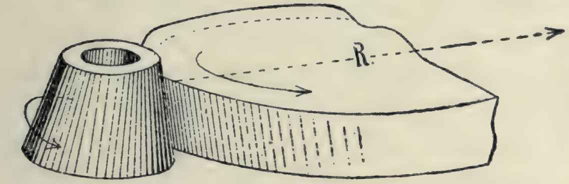


Fig. 74.
Conical plane cut with a conical cutter the axis of which is rectangular on the milling table.

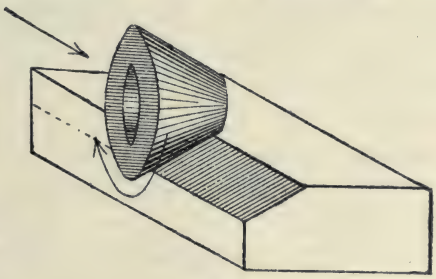


Fig. 75.
Slope plane cut by conical cutter.

In the same way, oblique planes can also be cut with a fixed horizontal spindle, (figs. 75 and 76), whilst dove-tail grooves can also be milled with a conical cutter (fig. 77).

Although in fig. 77, the cutter is working in the full material, it is nevertheless advisable to mill as large a groove as possible beforehand, not only on account of the time taken up by milling but also to spare the cutter.

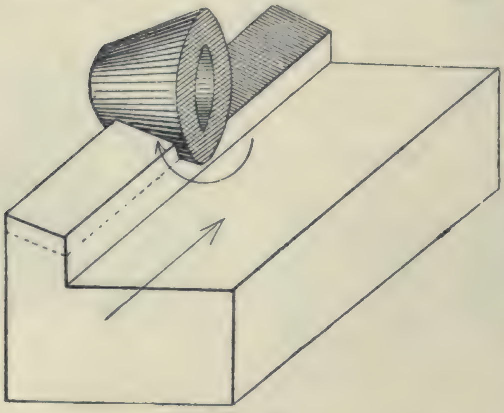


Fig. 76.
Sloping plane cut by conical cutter.

All the operations which have been considered so far, have been carried out by means of a milling cutter, the general type of which was shown in fig. 29.

Fig. 78 represents the working method with an end mill as illustrated in fig. 15. In this case, the diameter of the cutter considerably exceeds the width of the plane to be milled; in fig. 79, the end mill is shown milling a keyway, but as only the front is toothed so that it is impossible to take a deeper cut than the depth of the teeth, it is necessary to go through the same groove more than once.

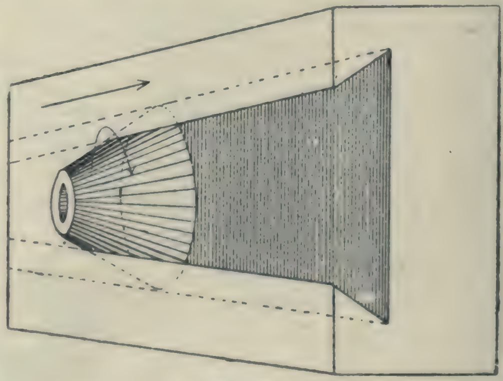


Fig. 77.
Dove-tail groove milled with conical cutter.

From this it is clear that this is not the right manner of working and that it therefore cannot be recommended. Fig. 80 represents a similar case in which a T slot has to be cut, the sides of which must each be cut seperately with due regard to the size.

b. THE MANNER IN WHICH THE CUTTER WORKS IN RESPECT TO THE PLANE OF MOTION.

In general, the formed cutter works horizontally to the plane of motion. Its use is practically limited to the manufacture of articles in quantities; in machine shops the percentage of milling work performed with the formed cutter is rather small. One of the most common forms of formed cutters is certainly the gear cutter, fig. 81. In general machine construction as well as for machine tools, the composed formed cutter is extensively used.

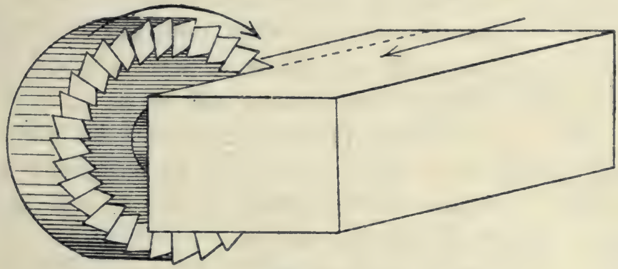


Fig. 78.
Face milling with an end mill.

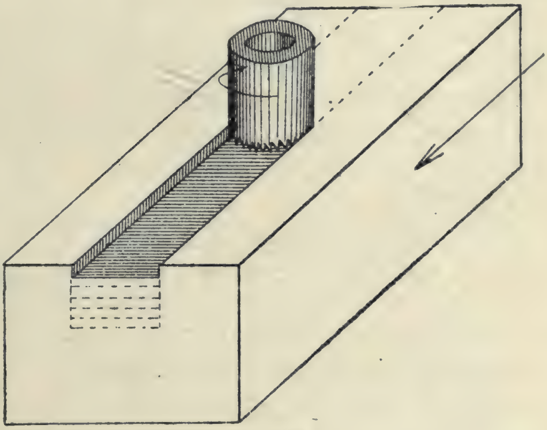


Fig. 79.
Milling a keyway with an end mill.

The formed cutter, which at the present day is almost universally known as the backed-off cutter, has a manner of working which makes it difficult to say when it is cutting as a shell mill, when as an end mill or when as a combination of both. Fig. 81 serves as an example of what is meant. The two sides work as an end miller, cutting away the material at the sides. The greatest diameter, the circumference, on the other hand, acts as a shell mill, but it is difficult to point out the exact spot where it begins to work as a shell mill or as an end mill; it is nevertheless a fact that the ends of the sides act more as a shell mill than an end mill; further consideration shows that on the greatest and smallest diameters the teeth mosty act in the same manner as an shell mill, whilst a cutting action can only be expected from the sides, seeing that they do not yet form a rectangular plane in regard to the centre line of the spindle. Where this is the case, as in fig. 82 for example, where the teeth at the side cannot cut but are only rubbing, the cutting of the ordinary backed-off cutter is practically not worth taking into consideration.

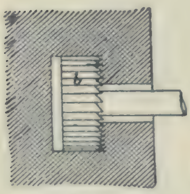


Fig. 80.
Milling a T slot with an end mill.

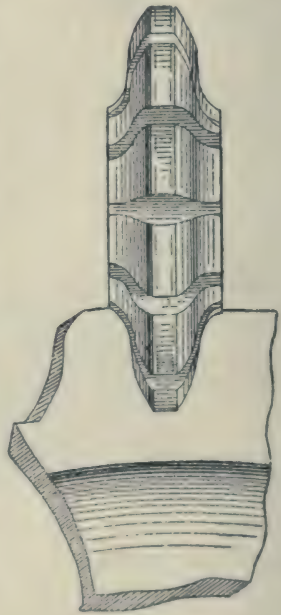


Fig. 81.
Backed-off gear cutter.

This defect of the backed-off cutter is not very serious when the movement of table and workpiece is rectangular to the centre line of the cutter, but it is more so when the relative positions are oblique, so that the workpiece is fed in somewhat to one side and still more so, when in addition to a movement in a straight line, a rotating motion is also imparted to the workpiece. In figs. 83—89, three positions are shown in which it is possible for the cutter to come, in respect to the feed movement of the table, viz: — figs. 83—85 give the most favourable position, i. e. the feed is rectangular to the centre line of the cutter. In figs. 86—87, the workpiece is fed in in an inclined plane in respect to the course of the spindle and moreover completes a rotating movement which causes the milling of a spiral. In figs. 88—89, the movement is parallel to the centre line of the spindle so that the material is cut away almost exclusively by the sides of the cutter.

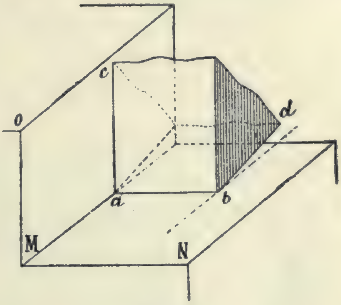


Fig. 82.

In these and similar cases, recourse has had to be taken to another method of constructing the backed-off cutter and as a result Reinecker's oblique backed-off cutter, (fig. 90) has come into existence, whilst for larger dimensions of the side flanks, the cutter is formed of two parts, the one with left hand and the other with right hand backed-off teeth (figs. 91 and 92). Fig. 92 shows the cutter disconnected; the guide, which can be seen separately, serving for the exact centering of the two parts: fig. 91 shows the cutter ready for use.

c. THE MANNER IN WHICH THE CUTTER WORKS IN RESPECT TO THE CUTTING PLANE.

It is always advisable when deciding on the form of the cutter, to take into consideration the manner in which it will cut.

It is quite possible to obtain the same result with two cutters of wholly different form; the one will quickly wear out while the other will remain in good condition a much longer time.

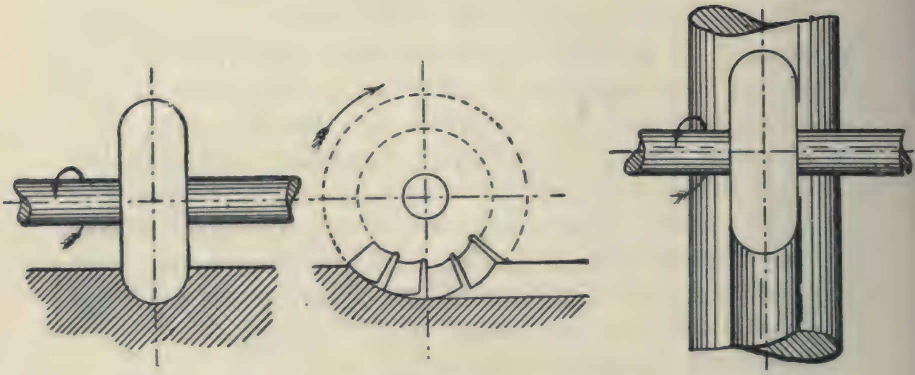


Fig. 83. Fig. 84. Fig. 85.

Formed cutter milling a groove rectangular on the spindle.

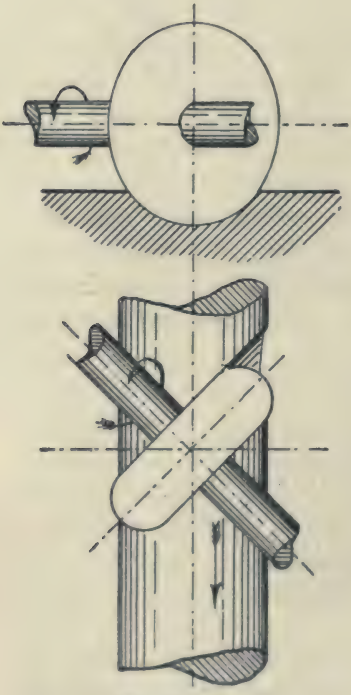


Fig. 86–87.

Formed cutter milling a spiral groove.

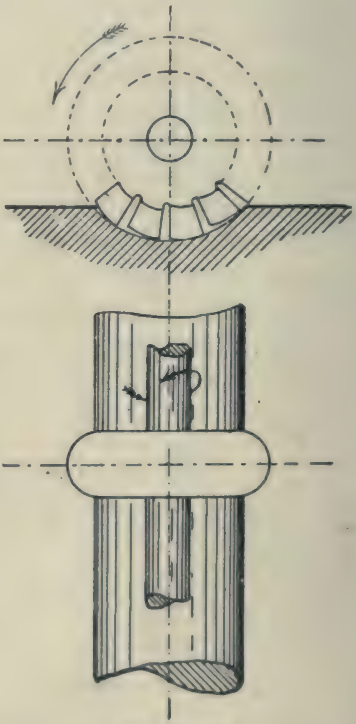


Fig. 88–89.

Formed cutter milling a groove parallel with the spindle.

This, as also the rotating direction of the workpiece with regard to the form of the teeth, will have to be taken into consideration, especially in the case of spiral teeth. With cutters such as those shown in figs. 94 and 95, precisely similar results can be obtained; the only thing that is necessary being to adjust the position of the workpiece with regard to the cutter, taking care that the line *a b* always passes through the centre *o*.

It is clear that the teeth *b c* on the contour of the cutter in fig. 94 have to do all the cutting, the side teeth being relieved from doing any work, whilst in the case of the cutter in fig. 95, the teeth on both sides cut away the material, so that the strain imposed on those teeth is much less. The angle of the teeth in regard to the centre line of the cutter may practically be determined at will; an angle of 75⁰ from one of the side flanks in regard to this centre line may be regarded as sufficient; both angles may, however, be made equal, as shown in fig. 96 and the same groove be milled. With the cutter as shown in fig. 96 the right or lefthand rotation of the workpiece exercises no influence on the working of the cutter, but with varying angles, (see fig. 96), the workpiece must rotate against the angle which is least acute. Figs. 97—100 give the exact movements of two cutters rotating in opposite directions.

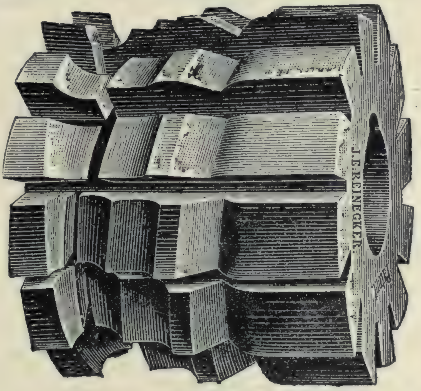


Fig. 90.
Backed-off cutter.

The plain milling cutter is by far the most frequent and the range of work for which it can be employed is illimitable. For this reason, the milling cutter in its simplest form is a tool that cannot be valued too highly for general machine construction. It can do the work of the planing and slotting tools in a thousand cases and not only that, but it does the work quicker, better and cheaper, whilst if it is properly handled, the plain miller is,

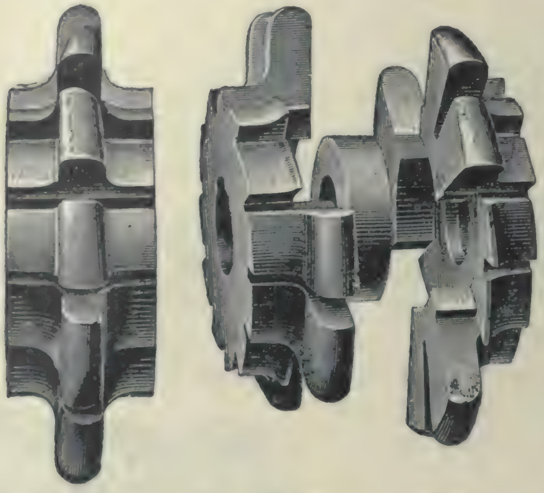


Fig. 91. Fig. 92. Fig. 93.
Oblique backed-off cutter with left and right hand halves.

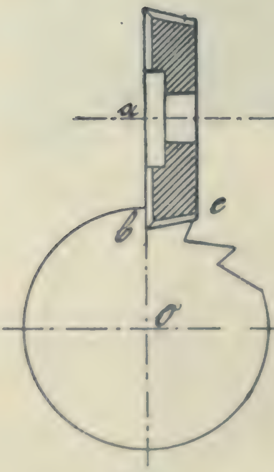


Fig. 94.
Cutter with one square side.

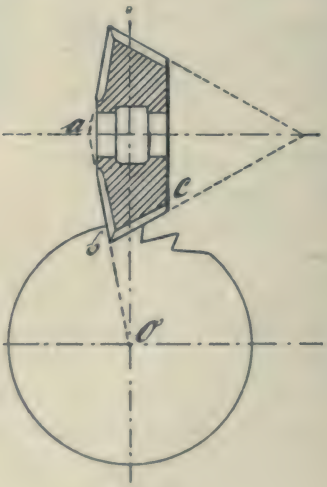


Fig. 95.
Double angle cutter.

by no means the dearest but rather the cheapest tool, as this same plain miller can be used in hundreds of different cases for which tools of other forms and dimensions would have to be provided if the work had to be performed with the planing or slotting tool.

The milling cutter is, therefore, worthy of our best attention, but only when the way of handling the cutter is thoroughly understood can this tool be estimated at its true value.

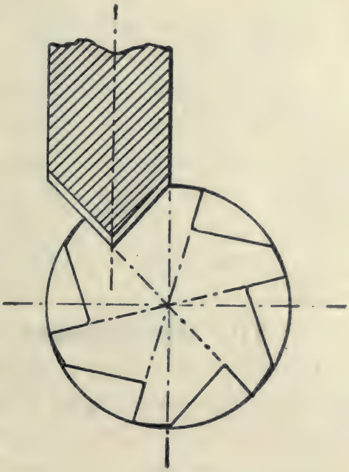


Fig. 96.
Double angle cutter with equal angels.

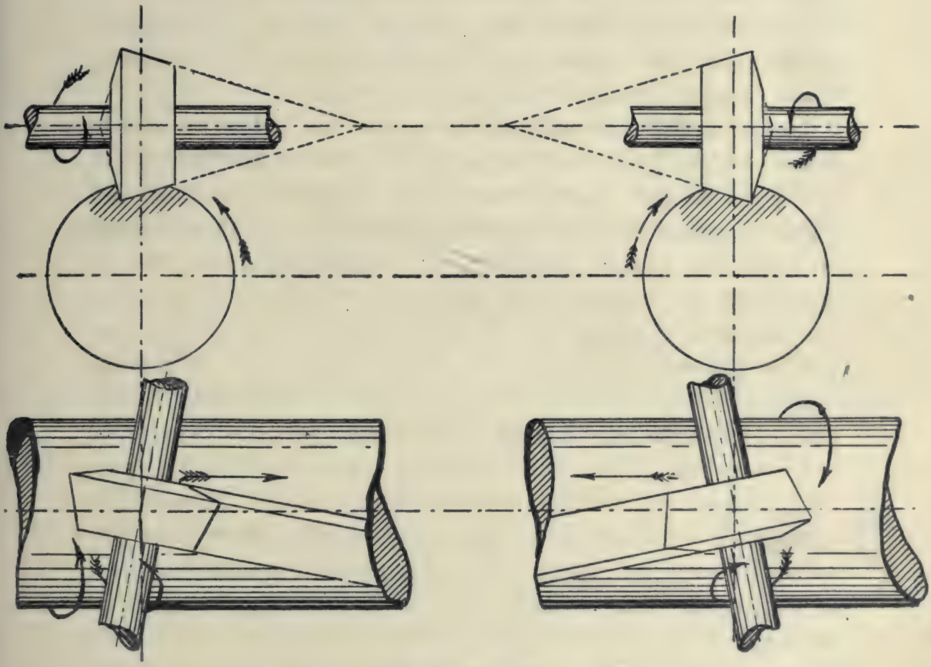


Fig. 97—100.
Movements of cutter and workpiece in milling spiral grooves.

CHAPTER V.

The construction of the Milling Cutter.

a. DIAMETER AND NUMBER OF TEETH.

Whenever an object has to be made or constructed, the most important point to be considered is its size. This is also the case as regards the construction of a milling cutter, (if the determining of the dimensions, the number of teeth, the angle of the teeth, etc. may be regarded as the construction of the cutter), the primary question being as to what diameter must be chosen.

In connection herewith no hard and fast rules can be laid down which have as their basis a common starting point, and it is for this reason that practical experience is of such supreme importance in deciding this question. The foreman or workman gauges, with his eye the diameter required for the cutter for certain work, so that it can thus be said that the diameter may practically be determined at will.

The greatest experience in the manufacture of milling cutters will be found in those factories which make a speciality of supplying cutters to the trade, but, however much one may rely upon their ability to give reasons for cases which regularly occur as to why they would, in a particular case, give a cutter a certain diameter, the nature and circumstances of the work which the cutter must perform are, as has been clearly explained in the preceding chapter, of so unlimited and divergent a character, that it is wholly impossible for them to inform the purchaser precisely within what limits a cutter of certain diameter can be used or within what limits a cutter of larger or smaller diameter should be employed.

Although the choice of the diameter cannot thus be confined within certain defined limits, still there are a few circumstances which can give some indication with respect thereto and especially when these circumstances are just the opposite, there will be a point where the advantages of the one will not counterbalance the disadvantages of the other and on this account the diameter can to a certain extent be determined. One must always be carefull not to let the diameter be too small for the following reasons, viz: cutters which are mounted on a spindle, have a bore, and the cutter with a diameter approximating too closely to that of the bore, will be weak and difficult to handle.

Cutters which are not mounted on a spindle but form one piece with the cone, i. e. end mills become weak, vibrate and are liable to breaking off. Moreover with a large cutter, a much smaller number of teeth are engaged on the work at the same time under otherwise similar circumstances, consequently, the heating of a cutter of larger diameter will not be as great as that of a smaller one, where as many as half the number of teeth may be engaged on the work at the same time. For these reasons, as stated above, one will generally be inclined not to choose a cutter with too small a diameter.

On the other hand, a cutter with too large a diameter is still less desirable than one with too small a diameter.

In the first place, the cost is much greater in the case of a cutter with a larger diameter than for one of smaller dimensions, whilst the possibility of cracking in the hardening is much greater with the former than with the latter.

At the same time the diameter of the cutter can cause a considerable difference in the time required for cutting away a certain thickness of material just because in reaching to and receding from the work the diameter exercises a great influence on the time required for milling certain pieces. Suppose for instance, that in fig. 101, a certain depth *a. b. c. d.* has to be removed from the workpiece P.

and that a cutter D. is employed for that purpose. Then, either this cutter or the workpiece will have to traverse a distance A B from point *b* where the teeth first come in contact with the workpiece to point *d* where the last material is cut away.

If, however, a cutter D_1 is employed the distance which the cutter or the workpiece must traverse in order to remove the same quantity of material will be represented by the line $A_1 B_1$ which is shorter and consequently requires less time than the distance A B. Accordingly, the greater the difference in diameter between D and D_1 or R and r, the greater will be the difference between A B and $A_1 B_1$. With respect to the diameter of the cutter this difference can be expressed in a stated formula, since

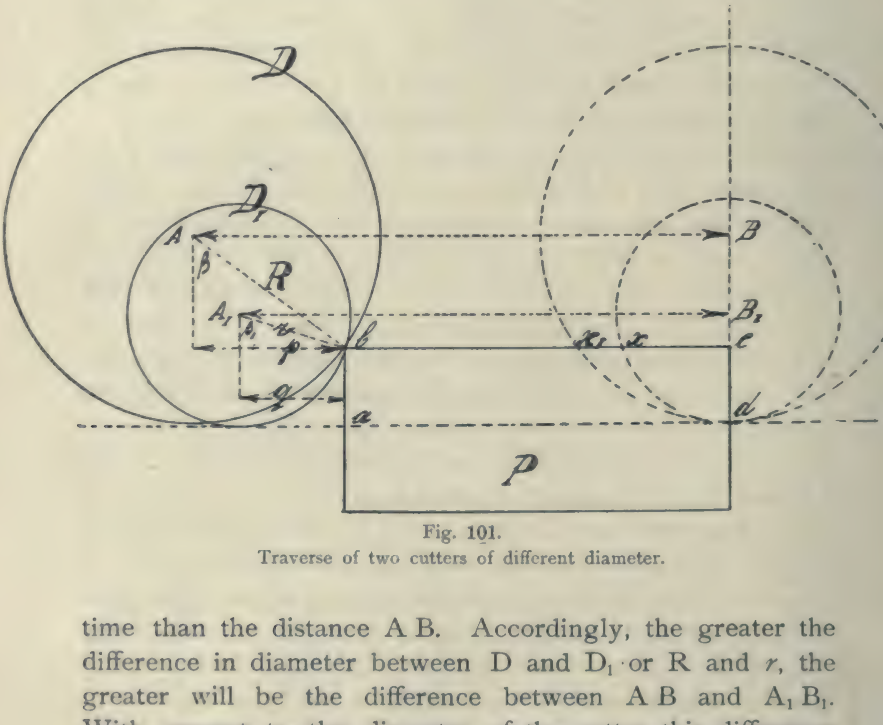


Fig. 101.
Traverse of two cutters of different diameter.

$$A\,B = A_1\,B_1 + p - q$$
$$p = R \sin \beta$$
$$q = r \sin \beta_1$$
$$\text{further } A\,B = A_1\,B_1 + R \sin \beta - r \sin \beta_1$$
$$\text{so that } A\,B - A_1\,B_1 = R \sin \beta - r \sin \beta_1.$$

If therefore, the feed is the same for both cutters and this feed per second is denoted by S, the removal of the depth *a. b. c. d.* by the cutter D will require $\frac{p-q}{S}$ seconds longer than that with cutter D_1.

The distance, i. e. the feed, traversed by the workpiece per second is, however, very small, so that the value of the fraction $\frac{p-q}{S}$ will quickly increase very considerably.

Suppose for instance, that fig. 101 is drawn to a scale of 1 : 2 and that 1000 of the workpieces P have to be milled, and that futher the feed amounts to $^1/_{32}$ inch per second, the difference in time required by the cutters D or D_1 will amount to: —

$$1000\,\frac{p-q}{S} = 1000\,\frac{^1/_2}{^1/_{32}} = 1600 \text{ secs. or about } 4^1/_2 \text{ hours.}$$

The time, therefore, that would be required for milling 1000 pieces with the cutter D_1 would be: —

$$1000\,\frac{A_1\,B_1}{S} = 1000\,\frac{5\,^1/_8}{^1/_{32}} \text{ seconds} = 46 \text{ hours.}$$

Similarly with the cutter D the time would be: 46 hours + 4 hours 30 min. = 50 hours 30 min., thus entailling a loss of time of about 10 % and consequently making the cost of production 10 % higher the time taken up for fixing and taking off need not be taken into consideration as this will be precisely the same in both cases. This will, however, naturally affect the percentage to a certain extent.

Viewed from this point, it is certainly worth while to devote sufficient attention to the diameter of the cutter.

In the foregoing there is evidently still something contradictory, seeing that with the same feed, the cutter D removes a plane of metal equal to $x_1\,d \times b$, if b is the width of the workpiece P; with the cutter D_1 on the contrary, this will be $x\,d \times b$ and $x_1\,d$ being longer than $x\,d$, more material will be cut away per unit of time by the larger cutter than by the smaller, whilst the time required for the whole work will still be longer for the larger cutter. The reason of this is that the cutter D_1 is already fully engaged after it has traversed a distance $c\ x$ from the first contact with the material whilst the cutter D has to traverse a distance $c\ x_1$ for the same purpose.

As long as the cutter D has a full cut on the work, it gains on the cutter D_1, but loses so much time at the beginning and the end that this results in a total disadvantage for the cutter D.

For this reason, the cutter should always be chosen with a diameter as small as is consistent with practical utility.

In this respect two possibilities have to be taken into consideration, viz: — the cutter which is mounted on an arbor: (see fig. 39), and the end mill with taper shank (see fig. 38).

The first type of cutter must from its very nature have a minimum diameter owing to the bore, the latter, on the contrary can have a very small diameter which, however, owing to other considerations, must still remain within certain limits.

In the first place the proportion of the length of the cutter must be considered with respect to the diameter, which proportion can generally be determined as 4 : 1, i. e. the diameter will be $^1/_4$ of the length of the teeth. Exceptional cases deviate from this, but there is a limit where the diameter of the cutter will be too small in proportion to the length, and the cutter will be either very difficult to harden, get out of true in this operation, or it will not be strong enough, will vibrate and run the chance of breaking.

Further the number of teeth diminishes in proportion to the reduction of the diameter, or, if the number remains the same, the thickness of the teeth will be reduced and a reduction of the thickness entails a diminution of the strength of the teeth. A reduction of the number of teeth, however, increases the work proportionally which each tooth has to perform, which by the same depth of cut may be regarded as a diminution of the strength of the tooth. Taking this into consideration, an excessive reduction of the diameter of the cutter may thus be very disadvantageous.

In order to secure a smooth, even working of the cutter, at least 2, if possible 3 or more teeth should be at work at the same time, the highest speed at which the cutter may rotate being further taken into consideration and in connection therewith the diameter of the cutter must be of such dimensions, as to obtain a sufficient circumference speed.

With the old European type of cutter the pitch was generally taken 0,1 D, so that if P = the pitch and t = the number of teeth,

$$t = \frac{\pi D}{P} = \frac{3.14\ D}{0.1\ D} = \infty\ 32.$$

At that time there was no uniform idea as to construction, as the strength of the teeth diminished with a reduction of the diameter or increased with an increase of diameter without any apparent reason.

Formerly, the diameter of the millers did not differ much so that this did not cause any great difficulty; though with the diversity of diameter met with at the present day, it would be quite impossible to fix upon an exact number of teeth.

The general formula however remains that if P = Pitch and t = the number of teeth

$$P = \frac{\pi D}{t} \text{ and } t = \frac{\pi D}{P}.$$

It goes without saying that there must be a certain relation between the diameter of the cutter and the thickness of the teeth, as also with the number of teeth with a fixed limit for the thickness of the teeth. A formula which has always served us excellently and has proved good in practice is, according to Knabbe, $P = 1{,}2 \sqrt{D}$. D being expressed in m.M.

The following table of the diameters of cutters most frequently met with has been compiled according to this formula.

Table I.

Table for determining the pitch and number of teeth for cutters of a given diameter.

D Diam. of cutter. mM.	P Pitch mM.	t No. of teeth.	D Diam. of cutter. mM.	P Pitch. mM.	t No. of teeth.
20	5.23	12	100	12.07	26
30	6.73	14	110	12.77	27
40	7.85	16	120	13.46	28
50	8.72	18	125	13.53	29
60	9.42	20	140	14.18	31
70	9.99	22	150	14.72	32
80	10.92	23	175	16.14	34
90	11.30	25	200	16.19	37

Only a few of the diameters of cutters which are met with in the trade have been given in table I, whilst with the formula referred to, the number of teeth for any other diameter can be found. The pitch is first calculated according to the formula so that after the number of teeth has been fixed upon, the exact pitch can be definitely settled.

For instance, a cutter of 250 mm.

$$\text{then } P = 1.2\sqrt{250} = 18.96 \text{ m.m.}$$

$$t = \frac{\pi D}{P} = \frac{785.4}{18.96} = 41.3.$$

In this case 41 teeth will be chosen.

If 41 teeth, then the actual pitch will be $\frac{785.4}{41.3} = 19.15$ m.m.

b. THE TOOTH AND ITS INCLINATION.

In order to ensure a really good construction of the cutter the inclination of the teeth is of quite as much importance as the pitch or the number of teeth, as its angle is closely associated with the pitch and the number of teeth.

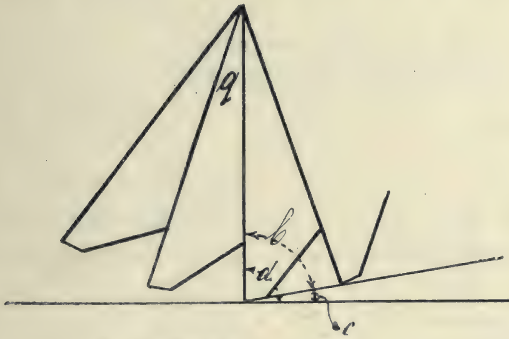


Fig. 102.

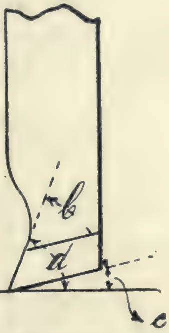


Fig. 103.

Angles of teeth.

In connection with the teeth of the cutter, the following angles have to be considered, (see fig. 102), viz:—

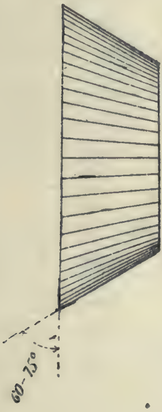


Fig. 104.
Angle cutter.

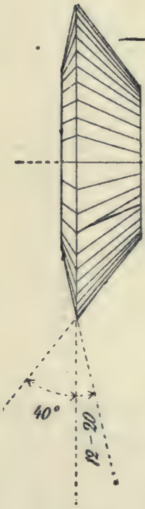


Fig. 105.

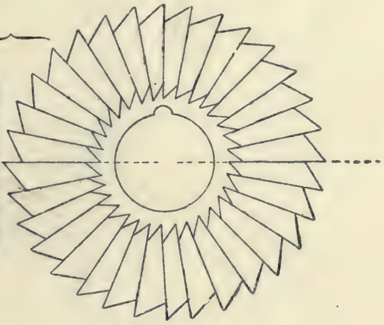


Fig. 106.
Double angle cutter.

q = that portion of the circumference of the circle occupied by one tooth.

d = the angle formed by rake and the plane of the workpiece.
b = the angle of the tooth.
c = the cutting angle.

If the teeth be taken separatly, the angles b, c, and d, are also to be found by lathe and planing tools, (fig. 103).

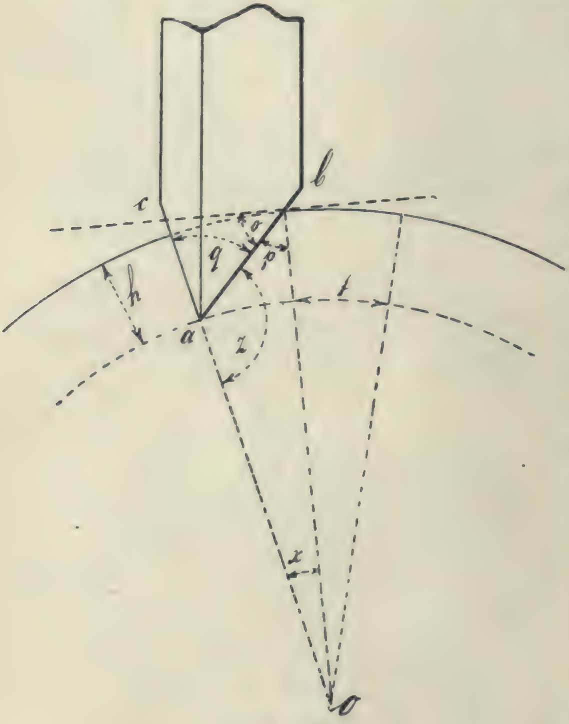


Fig. 107.
Angle of cutters.

Angle q is quickly determined as depending upon the number of teeth; thus $q = \frac{360}{t}$.

The teeth of a cutter are milled by another cutter and for this purpose either a cutter similar to that shown in fig. 104 or one like that illustrated in figs. 105 and 106 can be used.

The angle of the types of cutter shown in fig. 104 varies from 60° to 75°, in figs. 105 and 106, the sharpest angle varies from 12° to 20° so that the angle which is milled by this cutter varies from 52° to 60°.

As to the use of one of these types of cutters, see what was said in connection with figs. 95 and 96.

52° to 75° can thus be accepted as the greatest deflection of the angle which should be cut.

In fig. 107, if the angle q is known, as likewise the angle

x from the number of teeth, the angle p can consequently be determined, since

$$p = 180^0 - (z + x)$$

$$\text{and as } z = 180^0 - q$$

$$p = q - z$$

The following table gives the different angles of x and p for the pitch given in table I.

Table II.

Table of angles of x and p for a given diameter and pitch.

D diam. of cutter. mM.	t No. of teeth	$< x$ No. of degrees	$< p$ No. of degrees
20	12	30.	22.
30	14	25.43	26.17
40	16	22.30	29.30
50	18	20.	32.
60	20	18.	34.
70	22	16.22	35.38
80	23	15.38	36.22
90	25	14.24	37.22
100	26	13.51	38.9
110	27	13.20	38.40
120	28	12.51	39.9
125	29	12.25	39.35
140	31	11.37	40.23
150	32	11.15	40.45
175	34	10.35	41.25
200	37	9.44	42.16

Angle O the angle originally milled, which is equal to $90^0 - p$ is very large; much too large in fact, to obtain good results when cutting. It is however, necessary for it to be so large in order to get a cutter which allows of sufficient clearance for the chips as well as to allow of regrinding when the cutter has become dull. For this reason the sharp edge is ground after hardening so that angle p

which is much too small and angle O which is much too large are replaced by angles p_1 and O_1 fig. 108 which can now be given the most advantageous angle for cutting. To obtain this the portion *a. b. c.* is ground off from the upper edge of the tooth.

For the purpose of distinctness, the portion to be ground off has been purposely enlarged in the drawing fig. 108; in practice, the rake *a c* of a new cutter may not exceed $^{1}/_{64}''$.

The grinding of rake *a c* is a matter of the greatest importance for the good working of the cutter, not only with reference to the quality of the work, but also with reference to the power required; by far too little attention is paid to this particular. Most factories *buy* their cutters; such cutters will be properly constructed and will come from the factory ground to the correct angle, but the regrinding, which will be done at the works where the cutter is in use, will not be carried out properly, and one of the first conditions for a good cutter, viz: the exactness of the angle O, will be neglected.

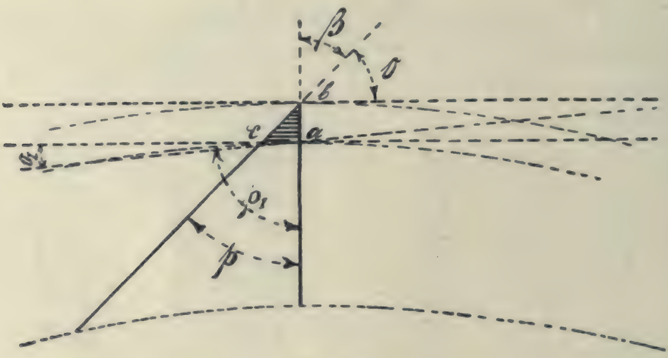


Fig. 108.
Cutting angles.

It is impossible to emphasize this point too strongly seeing that the rake *a c* is too small to permit of the cutter being altered after grinding; the greatest attention must be directed to the correct position of the cutter with regard to the emery wheel with which it is ground.

Angle O_1 may vary from 3^0 for hard to 12^0 for soft material, the intermediate angles can be determined for different kinds of material. However, to avoid the necessity of having an excessive number of cutters, 3^0 to 6^0 is generally adopted for hard and 7^0 to 12^0 for soft material.

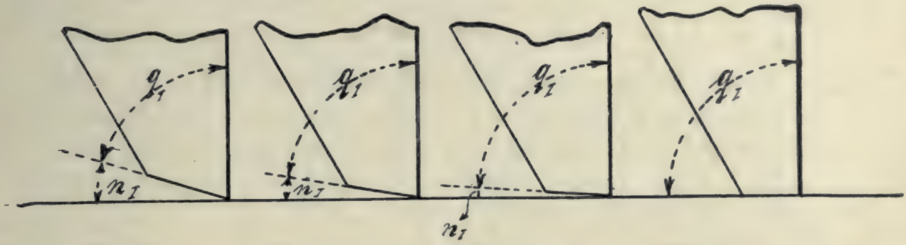


Fig. 109. Fig. 110. Fig. 111. Fig. 112.

Cutting angles of millers.

Fig. 109 $q_1 = 75^0$, $n_1 = 15^0$ (too sharp).
Fig. 110 $q_1 = 80^0$, $n_1 = 10^0$ (angle of teeth for soft material).
Fig. 111 $q_1 = 86^0$, $n_1 = 4^0$ (angle of teeth for hard material).
Fig. 112 $q_1 = 90^0$, $n_1 = 0$ (ground too obtuse or teeth have become dull.

The limit up to which material can still be cut away is $q_1 = 90^0$, as soon as q_1 exceeds 90^0 further cutting becomes impossible.

The necessity of keeping the teeth of the cutter sharp cannot be too strongly insisted upon, since when once the sharp edge is off, and a large portion of the plane *a c*, (fig. 108), still remains, a new plane is really formed, viz: — q_{II} which is an angle of 90^0. Some makers of cutters stamp on their goods the warning "grind frequently" so that this weighty factor may be continually borne in mind.

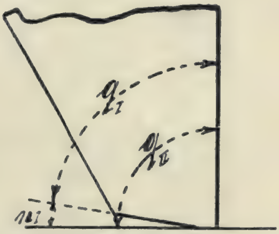


Fig. 113.
Cutting angle.

The depth h of the teeth can now further be calculated from fig. 107, provided the angles x and p are known as also the diameter of the cutter.

$$h = \frac{D}{2} - O\,a = \frac{D}{2} - \frac{D \sin p}{2 \sin z} = \frac{D}{2}\left(1 - \frac{\sin p}{\sin (180\text{-}q)}\right)$$

from which follows that:

$$h = \frac{D}{2}\left(1 - \frac{\sin p}{\sin q}\right)$$

If the angles known from table II are substituted in this formula for D, x and p, the exact depth h of the teeth can be calculated for each cutter which is mentioned in table III according to the diameters given in table II, whilst, at the same time, the ratio of the depth to the pitch $\frac{h}{P}$ and of the depth to the diameter $\frac{h}{D}$ are also included.

It will be seen from table III that the depth of the teeth for diameters from $^3/_4''$—$8''$ varies from pitch to 0,87 pitch which for sizes so divergent is decidedly but a slight difference. The average depth of the teeth with regard to the pitch can thus be generally fixed as

$$h = \frac{1 + 0{,}87}{2} p = 0{,}93\, p.$$

Table III.

Table of depth of teeth and ratio h : D and h : P for a given diameter of cutter.

D Diam. of cutter.		h depth in mM.	$\frac{h}{D}$	$\frac{h}{P}$
Inch.	mM.			
$^3/_4$	20	5.3	0.26	1.—
$1^3/_8$	30	6.6	0.22	0.99
$1^9/_{16}$	40	7.6	0.19	0.97
2	50	8.3	0.16	0.95
$2^3/_8$	60	9.—	0.15	0.96
$2^3/_4$	70	2.1	0.13	0.91
$3^1/_4$	80	10.—	0.12	0.91
$3^1/_2$	90	10.3	0.11	0.91
4	100	11.—	0.11	0.91
$4^5/_{16}$	110	11.5	0.10	0.90
$4^{11}/_{16}$	120	12.—	0.10	0.89
5	125	12.5	0.10	0.92
$5^1/_2$	140	12.6	0.09	0.88
6	150	12.7	0.08	0.87
7	175	14.—	0.08	0.87
8	200	15.—	0.07	0.88

Table IV.

D diam. of cutter		t No. of teeth	P Pitch in mM.	h depth in mM.	$\frac{h}{D}$	$\frac{h}{P}$	$< x$ in °	$< p$ in °
Inch.	mM.							
$^3/_4$	20	12	5.23	5.3	0.26	1.—	30.	22.
$1^3/_8$	30	14	6.73	6.6	0.22	0.99	25.43	26.17
$1^9/_{16}$	40	16	7.85	7.6	0.19	0.97	22.30	29.30
2	50	18	8.72	8.3	0.16	0.95	20.	32.
$2^3/_8$	60	20	9.42	9.—	0.15	0.96	18.	34.
$2^3/_4$	70	22	9.99	9.1	0.13	0.91	16.22	35.38
$3^1/_4$	80	23	10.92	10.—	0.12	0.91	15.38	36.22
$3^1/_2$	90	25	11.30	10.3	0.11	0.91	14.24	37.22
4	100	26	12.07	11.—	0.11	0.91	13.51	38.9
$4^5/_{16}$	110	27	12.77	11.5	0.10	0.90	13.20	38.40
$4^{11}/_{16}$	120	28	13.46	12.—	0.10	0.89	12.51	39.9
5	125	29	13.53	12.5	0.10	0.92	12.25	39.35
$5^1/_2$	140	31	14.18	12.6	0.09	0.88	11.37	40.23
6	150	32	14.72	12.7	0.08	0.87	11.15	40.45
7	175	34	16.14	14.—	0.08	0.87	10.35	41.25
8	200	37	16.19	15.—	0.07	0.88	9.44	42.16

The ratio of the depth of the tooth with regard to the diameter is too diverse, (from 0,26 to 0,07), to permit of a ratio being fixed upon.

A smaller depth of tooth equal to from $^1/_3$ to $^1/_4$ of the depth of the tooth of a milling cutter is usually taken for end cutters.

Finally, table IV is a combination of tables I, II and III and by its use a well constructed, good working cutter can always be obtained for general purposes.

c. THE SPIRAL LINE OF THE TEETH.

Table III and what was previously said apply equally as well to cutters with straight as to those with spiral teeth; as however, the latter type of cutter lasts very much longer, turns out much better quality work and the spiral teeth increase to no small degree the cutting capacity of the cutter, whilst the milling machine itself suffers less by the use of spiral cutters, it is generally advisable to make as much use of the cutter with spiral teeth as possible. We say with reason as much as possible, because to make formed cutter with spiral teeth has even up to the present day presented certain insurmountable difficulties. Figs. 54 and 55 show how even if not actually a spiral, still an irregular line of teeth can be formed for some types of cutters; for plain and slitting cutters as also for conical cutters, the spiral form of teeth is much to be prefered.

The question as to the length of the spiral line partly depends on the diameter of the cutter, and partly on the width of the plane to be milled, with which is also included the fact that the length of the cutter should be chosen in accordance therewith.

The length of the spiral line can also be expressed by the inclination of the spiral line; moreover the determining of this inclination is necessary for the construction of the cutter. This is discussed in detail in Chapter VI in connection with the construction of the cutter.

The inclination of the teeth of spiral cutters varies in general from 20° to 30° which is equivalent to a pitch of from 7 to 9 times the diameter of the cutter. Although the leading manufacturers of cutters show a decided tendency to cut spirals to the smallest angle and still smaller, our own personal experience is somewhat opposed to this and cutters which we have made and which always approached the largest angle, have served us much better, whilst once, as an experiment, we cut a miller with a pitch equal to four times the diameter and that for an end mill of only 1 inch diameter; the cutting capacity was really surprising; but in such a case other difficulties are encountered, grinding especially becomes much more difficult, whilst with spiral end mills, an angle which is too large causes the front teeth to assume a very unfavorable angle. With spiral teeth the front rake of the front teeth is part of a spiral on the mill; it is thus only in the case of straight teeth that the front rake of the front teeth comes squarely on the plane of the work. With spiral teeth, the cutting angle of the front teeth is less than 90° and the smaller the pitch of the axial teeth, the smaller the angle, till at length, the cutting capacity is entirely lost owing to the unfavorable angle. (Fig. 114).

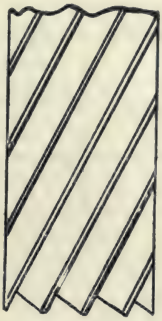


Fig. 114.
End mill with large inclined teeth.

Table V gives the different pitches with angles of from 15° to 30° for cutters of from $^3/_4$ to 8 inch diameter. For the calculation of the change wheels the pitch is given in round numbers and not the exact fraction.

The question as to whether a cutter shall cut to the right or left hand is also of interest.

On this depends also whether the spiral line has to be right or left handed. If the cutter on account of the rotating direction must rotate to the right, the cutter must have left hand spiral teeth, should it, on the contrary, rotate to the left, it must have right hand spiral teeth. (Figs. 115 and 116).

As they both rotate in opposite directions, the feed motion of the table must naturally be contrary to both.

If the milling machine can rotate at will and the feed motion be in two directions then for plain shell mils, the question as to the choice of a right or left hand cutter remains an open one.

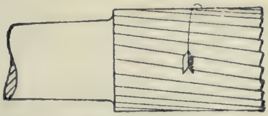


Fig. 115.
Left hand cutter.

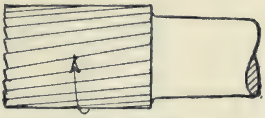


Fig. 116.
Right hand cutter.

The question here arises as to what kind of work the cutter has to perform.

The cutter has always to be selected so as to allow the chips to be released as easily as possible in order to prevent their clogging between the teeth and the surface of the work and so destroying the cutter.

Table V.

Table of pitch of the teeth of cutters for a given angle and diameter.

Diam. of cutter.	Pitch of the teeth at an angle of 15°	Pitch of the teeth at an angle of 20°	Pitch of the teeth at an angle of 25°	Pitch of the teeth at an angle of 30°
inches.	inches.	inches.	inches.	inches.
3/4	9 1/4	6 3/4	5 1/4	4 1/4
1	11 1/2	8 1/2	6 1/2	5 1/3
1 3/16	14	9 3/4	8	6 1/2
1 3/8	16 1/4	11 3/4	9 1/2	7 1/2
1 9/16	18 1/2	13 1/2	10 1/2	8 1/2
1 3/4	20 3/4	15 1/4	12	9 1/2
2	23	17	13 1/4	10 2/3
2 1/8	24 1/3	18	14 1/2	11 3/4
2 3/8	27 2/3	20 1/3	16	13
2 9/16	30	22	17 1/4	14
2 3/4	32 1/4	23 3/4	18 1/2	15
3	34 3/4	25 1/2	20	16 1/16
3 1/4	37	27	21	17
3 1/2	41 1/2	30 1/2	24	19
4	46 1/8	34	26 1/2	21 1/3
4 5/16	50 3/4	36	29	23 1/2
4 3/4	55 1/3	40 2/3	32	26
5 1/4	60	44	34 1/2	28
5 1/2	64 1/2	47 1/2	37	30
5 7/8	69 1/2	49	40	32 1/4
6 3/8	74	54	42	34
7	83	61	48	38
7 7/8	92 1/4	68	53	42 2/3
9 1/2	110 1/4	81 1/3	64	52

In ordinary surface work as shown in fig. 57, no trouble is experienced with the chips, but on the other hand the lateral pressure has to be taken into account. As the teeth of the cutter form a spiral, the cutter will experience a pressure either on one side or the other.

If the arbor on which the cutter is mounted runs free and fits in the spindle by means of a taper shank a right hand cutter with left hand spiral will then receive a pressure in a direction to the shank which will consequently be pressed more firmly into the taper. A left hand cutter will, on the contrary, be pulled out of the taper.

If the end of the arbor is supported by a centre, the spindle bearing will take up the pressure in the case of a right hand cutter; with a left hand cutter, this will have to be done by the centre which has only a small surface for the absorption of pressure. In all cases the preference is thus to be given to the right hand cutter.

For this reason, makers of cutters almost invariably supply right hand cutters unless otherwise stipulated in the order. It is, however, always advisable when ordering cutters to state that right hand cutters are required, but this is imperative, if left hand cutters are desired.

d. THE BACKED-OFF CUTTER.

The construction of a good backed-off cutter rests on an entirely different basis to that of the cutter with ordinary milled teeth; in fact, the whole construction of the backed-off cutter is different to that of the ordinary cutter. Without going directly into the question of grinding, it may here be pointed out that the method of grinding is entirely different for the two kinds of cutters. In the case of the ordinary cutter which has become dull, the teeth are ground on the back, along the line a b in fig. 117, which line makes a certain angle with the radius O a, of which the front of the tooth generally forms one line as well as with the tangent a P.

It is evident that as easy as it is to grind an ordinary straight tooth as represented in fig. 39, the grinding of the teeth of a formed cutter as shown in fig. 47 is just as difficult, nay, almost impossible and however ingeniously one may set to work, it is impossible to grind a cutter on the back of the teeth in the case of the more composite forms of the cutter.

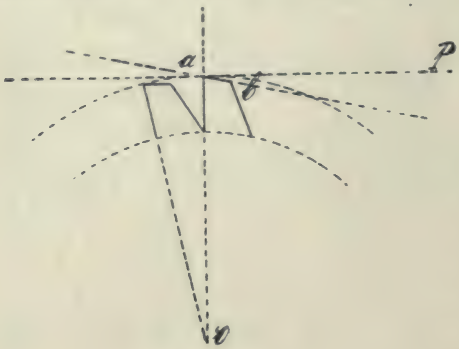


Fig. 117.

The invention of the backed-off cutter has therefore proved of the utmost importance in the development of milling and it has thereby become possible not only to render the grinding so very simple that, if necessary, it can be performed by an unskilled workman, but to guarantee the absolute similarity of the teeth both *before* and *after* grinding, so that the form, even after many times regrinding will not have undergone the slightest alteration.

A striking example of this is shown in the case of the cutter illustrated in fig. 118, which is preserved in Reinecker's museum. 200.000 triggers of Mannlicher rifles were milled with this cutter, which reckoning a thickness of $^{1}/_{4}$ inch each represent a total milling length of 4166 ft. Fig. 119 shows this cutter in its original

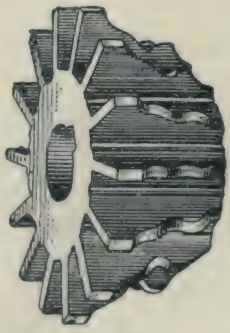


Fig. 118.
Worn out backed-off cutter.

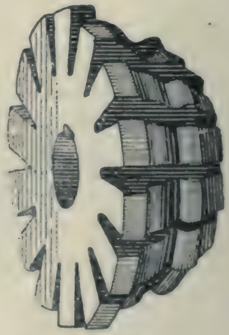


Fig. 119.
New backed-off cutter.

state whilst it can be seen from fig. 118 that, as a result of repeated regrinding, not more than $^{1}/_{5}$ of the original thickness of the teeth remained, but, notwithstanding this, the form of the last trigger was identical with that of the first.

The principle of the backed-off cutter is that the back of the tooth is formed according to the logarithmic spiral, which line has the property that at every point it forms with the radius one and the same angle. With the backed-off cutter, therefore, care has only to be taken that the rake forms a part of the radius in order to ensure perfect uniformity of its form.

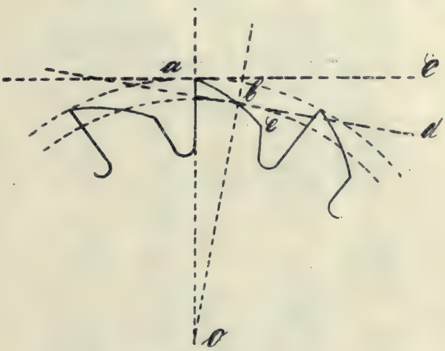


Fig. 120.
Teeth of backed-off cutter.

Thus, if in fig. 120, the tooth is ground to *b*, the angle O *b e* will still be precisely similar to the original angle O *a e*, whilst the angles *b a c* and *b e d* are also equal.

The number of teeth on the backed-off cutter is totally different to that of the ordinary cutter; various considerations which are of considerable importance with regard to the ordinary cutter, can be completely ignored in the case of the backed-off cutter. One of the chief conditions of the backed-off cutter is that the root of the tooth may not be weakened too much. With a straight groove, and this is almost universally adopted whilst in many cases where a deep groove is necessary on account of the form of the tooth, a straight groove is unavoidable, the root of the tooth will always be weaker than the end and therefore with millers of small diameter, a pitch varying from $1''$—$1^{1}/_{2}''$ is sometimes necessary.

Table VI.

Table for backed-off cutters.

Diameter of cutter in inches.	No. of teeth.	Depth of tooth in inches.
$^3/_4$	8	0,208
1	9	0,23
$1^1/_4$	9	0,275
$1^1/_2$	10	0,29
$1^3/_4$	11	0,3
2	12	0,343
$2^1/_2$	14	0,36
$2^3/_4$	15	0,38
$6^1/_4$	17	0,39
$6^1/_2$	18	0,41
4	19	0,434
5	22	0,45
$6^1/_4$	25	0,46
6	27	0,458
7	30	0,48
8	34	0,49

No universally adopted construction exists for backed-off cutters. Every expert who has used backed-off cutters to any extent, employs the results of his own experience in the manner in which he considers the best results are obtainable. Table VI, (although it must be distinctly understood that it cannot be accepted as universally applicable), yields excellent results in the majority of cases.

The depth of the tooth, which is also the depth of the groove, has been taken as equal to $^2/_3$ of the pitch. With a larger pitch, $^1/_2$ pitch will possibly suffice but a depth of tooth which exceeds $^2/_3$ of the pitch cannot be recommended, the more so that, as the depth of the groove increases, the strength of the tooth diminishes.

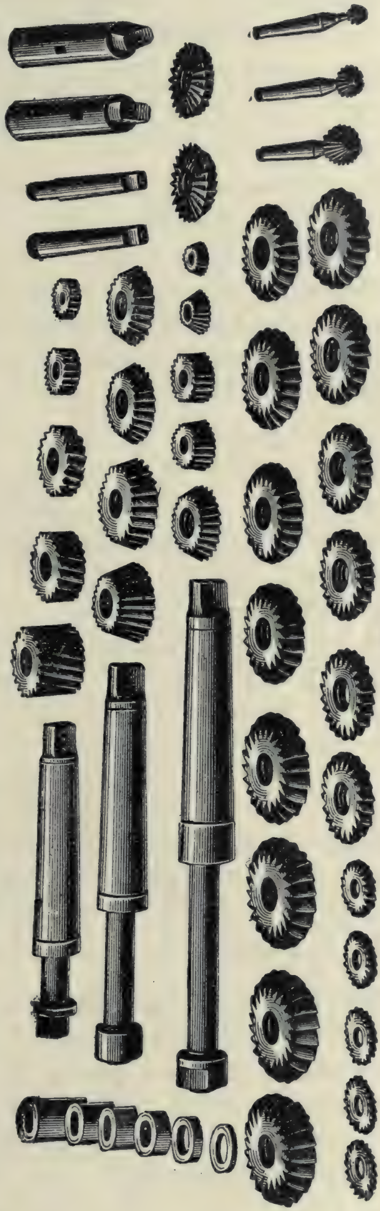


Fig. 121.
Various types of cutters.

e. THE BORE OF THE CUTTER.

A very large number of cutters are provided with a bore and mounted on an arbor. Every milling-machine is therefore supplied with a certain number of arbors of various diameter and length, whilst to avoid the necessity of having too many arbors for cutters of different length the thickness of which does not coincide with the length of that part of the arbor intended for mounting cutters, the remaining part is filled up with sleeves, (see fig. 121).

The arbors are provided with a cone, the end of which fits in the spindle of the milling machine, whilst the other end is hardened and provided with a centre supported by the overhanging arm of the machine. The conical bore in the spindle frequently corresponds to one of the numbers of the morse-cone, in which case, twist drills can also be used on the milling machine.

The shell end mills which are also provided with taper shanks corresponding to the dimensions of the cone fit direct in the spindle.

The dimensions of the cone which are bored in the spindle of the milling machine depend upon the size of the machine; the diameter of the arbor, on the contrary, is dependent on the bore of the cutter, which, in its turn depends on the diameter of the cutter and varies from $\frac{5}{8}$—$1\frac{3}{4}$ inch. Reinecker takes the following as the normal bore of cutters of varying diameter: —

for gear cutters:

D = to	$2\frac{3}{8}$	$2\frac{5}{8}$	$2\frac{3}{4}$—$3\frac{1}{2}$	$3\frac{3}{4}$—$4\frac{1}{2}$	5—6	inches.
d =	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	inches.

cutters for taps, twist drills, etc.:

D = to	1—$1\frac{3}{4}$	2—$2\frac{1}{4}$	$2\frac{5}{8}$—$3\frac{3}{8}$	$3\frac{1}{2}$—4	inches.
d =	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{7}{8}$—$\frac{5}{4}$	$1\frac{1}{8}$	inches.

for side milling cutters:

D =	2—$2\frac{1}{4}$	$2\frac{5}{8}$—$3\frac{3}{8}$	$3\frac{1}{2}$—4	$4\frac{1}{2}$—$6\frac{3}{4}$	7—1	inches.
d =	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	inches.

for plain milling cutters:

D =	2—$1\frac{2}{4}$	2—$2\frac{1}{4}$	$2\frac{3}{4}$—4	4—5	inches.
d =	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	inches.

for backed-off cutters: —

D =	2—$2\frac{1}{4}$	$2\frac{3}{8}$—$3\frac{3}{8}$	$4\frac{1}{2}$—$4\frac{1}{2}$	5—6	6—8	inches.
d =	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	inches.

D = diameter of cutter, d = bore of cutter.

One of the first requirements for the good working of the cutter is that the bore *fits exactly* to the arbor without any play.

In order to ensure a perfect fit without the cutter being actually tight fitted to the arbor, the cutter is provided with a recess, (Fig. 122), and the bore *a* and *b* is only ground *after* hardening.

The arbor is further provided with a keyway, the cutter having a corresponding keyway. The key in this keyway may not serve any other purpose than acting as a security. Under no circumstances may the key fit tight in the keyway of the cutter. The cutter must fit exclusively on the bore as otherwise it might possibly swing.

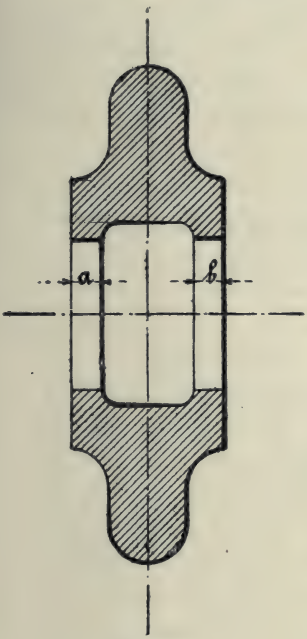


Fig. 122.
Cutter with recessed bore.

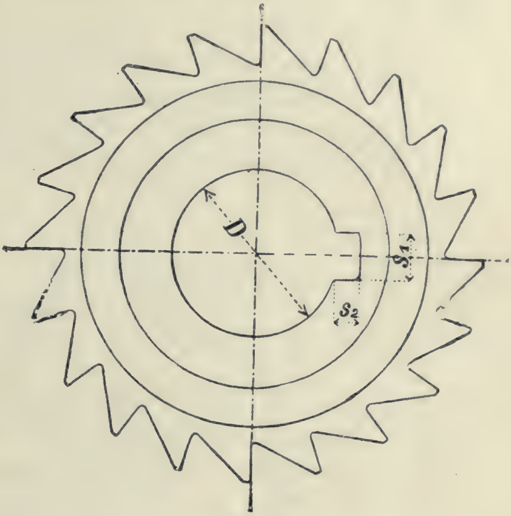


Fig. 123.
Square keyway with rounded corners.

Table VII.

Dimensions for square keyways with rounded corners.

Bore of cutter in inches.	With of keyway in inches.	Depth of keyway in inches.
D	S_1	S_2
3/8 — 9/16	3/32	3/64
5/8 — 7/8	1/8	1/16
15/16—1 1/8	5/32	5/64
1 3/16—1 3/8	3/16	3/32
1 7/16—1 3/4	1/4	1/8
1 13/16—2	5/16	5/32
2 1/16—2 1/2	3/8	3/16
2 1/2 —3	7/16	3/16

Table VII and fig. 123 give the dimensions of the keyways for the various bores according to Reinecker.

Loewe, Pratt and Whitney and others make a semicircular keyway, (fig. 124), to prevent cracking because of the keyway, which keyway is drilled in cutters of not too great a width in the full material before the central bore of the cutter is made.

In any case, the corners of the keyway should not be sharp.

The leading manufacturers are gradually fixing upon normals as given in table VIII for this purpose which are now generally followed.

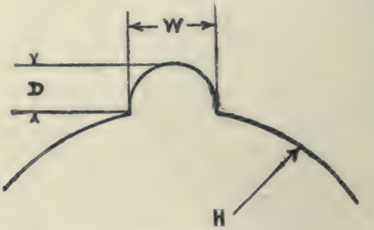


Fig. 124.
Semi-circular keyway.
See table VIII.

Table VIII.

Dimensions of semi-circular keyways.

Bore of cutter.	Diameter of semi-circular keyway W.	Depth D.
inches	inches	inches
3/8—5/8	1/8	1/16
11/16—13/16	3/16	3/32
7/8—1 3/16	1/4	1/8
1 1/4—1 7/16	5/16	5/32
1 1/2—2	3/8	3/16
2 1/16—2 7/16	7/16	7/32
2 1/2—3	1/2	1/4

CHAPTER VI.

The manufacture of cutters.

a. GENERAL CONSIDERATIONS.

The manufacture of cutters has in the last ten years reached such a degree of perfection, not only with regard to the quality and durability of the tool itself but also of its capacity, that one might almost speak of it as the acme of perfection.

It cannot be too strongly insisted upon to purchase the cutters which one may require from firms making a speciality of this manufacture and have thus obtained the necessary experience to turn out a cutter that really cannot be improved and that no one should endeavour to make their own cutters unless with sufficient means at their disposal in the way of machinery, tools, material and skilled workmen.

At the present time there are firms such as Pratt and Whitney, Brown and Sharpe and others to whom milling technic owe a deep debt of gratitude, who have set about the manufacture of cutters on such an extensive scale, that an inspection of their establishments is bound to convince one that such firms are in a position to supply the very best which the technical world in this branch has to offer. These firms manufacture cutters of every conceivable form, size and construction, and in addition, keep such an enormous stock such as surface, shell and angle cutters and end mills, etc. that it can be truly said that their manufacture has become a wholesale industry and one would require an exceptionally well-equipped toolmakers-shop to be able to turn out cutters at the prices for which they can be purchased at one or other of these factories.

Although, notwithstanding what has just been said, the manufacture of cutters is discussed in the following pages, this has been done since even if one purchases the cutters required, an acquaintance with the process of manufacture is a sine qua non to a good judgment of the tool to be used, as, owing to a variety of circumstances it is quite possible that one may be called upon to manufacture cutters oneself.

The cutter must be made of the very best quality steel. The cost of the steel required for the manufacture of a cutter is so small in proportion to the cost of manufacture, that the loss occasioned by the cutter not reaching such a high pitch of efficiency owing to its inferior quality, as one manufactured from first quality steel, cannot be very considerable. All economy in the choice of the steel to be used for the manufacture of cutters should, therefore, be set on one side.

The steel best adapted to the manufacture of cutters is that which is entirely free from all injurious elements such as sulphur, copper, phosphorus, etc. but contains a percentage of carbon varying from 0.9 to 1.45 %.

The old type of fine pitched cutter which can only cut away a very thin chip may, in contradistinction to those of the new type, the coarser teeth of which penetrate the material to be worked to a considerable depth and which are consequently exposed to a much higher pressure than the first-named, contain a higher percentage of carbon than the coarse pitched cutters, whilst the quality of the latter is considerably improved by adding Wolfram, Chroom or Mangaan to the steel from which they are made. Cutters made of Wolfram steel, in particular, excell on account of their excellent quality and take the leading place as regards cutting capacity.

Of late, since the introduction of high speed steel, cutters made from high speed steel have also been put on the market and have quickly won a place on account of their considerably greater capacity.

At the exhibition of machine tools held at Olympia, London in October 1906, we ourselves witnessed a milling cutter cutting a depth of $^3/_8''$ from a casting of 16″ long and 6″ wide in 1 min. 15 secs. Only a short time ago such tests would have been quite impossible.

Meanwhile the reason of the exceptional capacity of these cutters is attributable not simply to the addition of Wolfram, Chroom or Mangaan, but to a great extent to the peculiar method of heating and hardening. This process, together with the above-mentioned additions, gives the steel such resistance that even when heated to 400° C. it does not lose its cutting capacity.

The forging of the cutter is confined almost exclusively to cutting off a sufficient length from the bar and planishing surfaces. But seldom the cutter is forged in a special form whilst, as a rule, a cutter of a certain diameter is not made from a bar of smaller diameter as this would affect the quality of the steel.

Even at the first operation the quality and cutting capacity of the blank can be considerably injured by an unskillful treatment of the steel. The steel must be quickly raised throughout to a temperature just sufficiently high for forging.

Every part of the steel is permeated by a fine tissue of carbon; if, therefore, during the heating process, much oxygen comes in contact with the steel, the carbon unites with the oxygen and evaporates, so that, as a consequence, the cutting capacity of the surfaces and more particularly of the edges is considerably diministed. Especially when the heating is done in an open fire in which, moreover, ordinary sulphurous coal is burned the quality of the steel is injured. Only as a last resource should ordinary coals be used and even then the coals should be well burned dead: it is, however, far preferable to use charcoal.

The very best results are obtained when the cutters are heated in a furnace which excludes all possibility of cold air coming in contact with the heated steel. (fig. 125).

During the process of forging it is unavoidable that the steel becomes strained owing to the various parts not receiving precisely the same treatment or to their being more or less unequally heated and these strains will have to be removed by reheating and tempering. The further handling of the steel is at the same time, considerably facilitated by a proper tempering. After forging, when the steel has been heated throughout to an almost white heat, the fire is drawn from the furnace which, together with the cutter, is allowed to slowly temper. This will take from 24 to 72 hours.

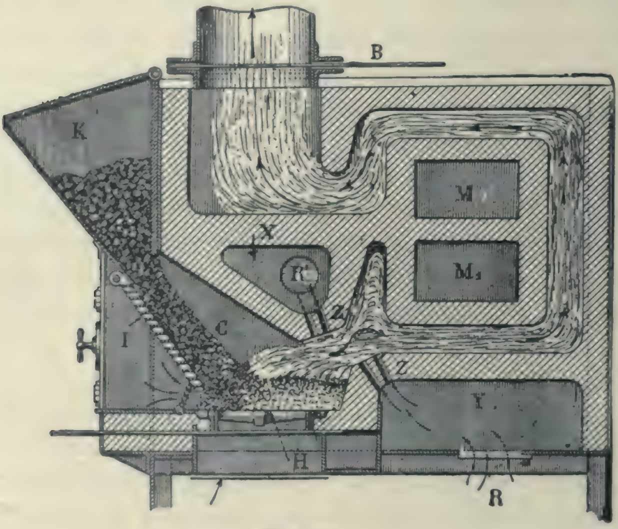


Fig. 125.
Heating furnace.

If one has not had sufficient practical experience in the handling of cutter steel, as it is so seldom that this has to be done in a workshop, it is advisable not to attempt it at all.

The leading tool steel works supply cutter sheaves all ready for mechanical treatment in various diameters, thickness and length as well as in different qualities so that one is certain of receiving a cutter forged without any mistake.

The bore. After tempering the rough cutter is turned and bored. In order to facilitate the grinding of the bore later on and to ensure the cutter fitting more accurately on its arbor, a recess is turned in the centre, (fig. 122), so that only two edges, about $^1/_4$ inch wide, remain of the actual bore at either side of the cutter. These edges are turned 0.01 inch smaller than the exact diameter for subsequent grinding.

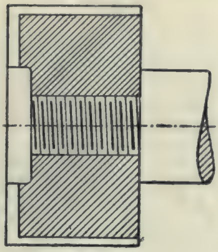


Fig. 126.
Threaded bore.

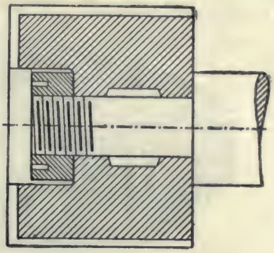


Fig. 127.
Recessed bore with nut-chamber.

Cutters having a threaded bore as also the chambers in cutters for nuts for fastening, (figs. 126 and 127), are not subsequently ground but are turned at once to size.

Fig. 128. End mill.

After this the cutter blank is mounted on an arbor and turned in the desired form.

End mills with cylindrical or conical shank, (fig. 128), are turned from the bar on the lathe. However, before proceeding to turn the cutter blank to the desired form, the two end surfaces must be straightened, after the piece of steel has been temporarily centered, the old centres being removed; it must then be re-centered and provided with centre holes (figs. 129 to 131). In this case also the conical or cylindrical shank must have an allowence of 0.02 inch for subsequent grinding, whilst the actual diameter is allowed to remain 0.02 inch for grinding.

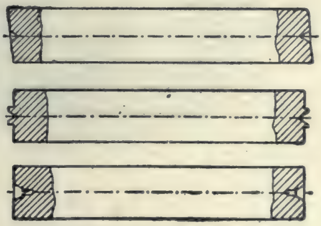


Fig. 129—131.
Centering of cutterblanks.

Cutting the teeth. Thus far there has been nothing special to mention in connection with the machining process, since giving the cutter blank its exact form on the lathe does not differ in the least from ordinary lathe-work; the cutting of the teeth, by which the cutter blank, whether sheave or bar, is now really given the form of a cutter, is a matter of far greater importance.

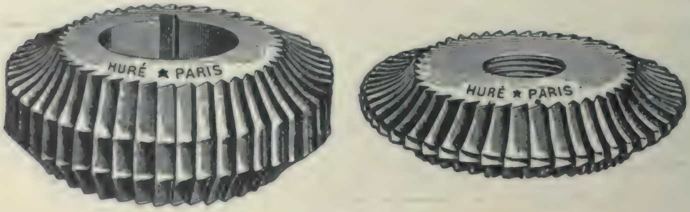


Fig. 132—133.
Cutters with fine pitched teeth.

The type of cutter is determined by the cutting of the teeth, the manner of working, the direction of movement, etc.

The teeth are cut on a milling machine by means of other cutters. The form and size of the cutters used for cutting the teeth depend on the form and very often on the dimensions of the cutter to be made.

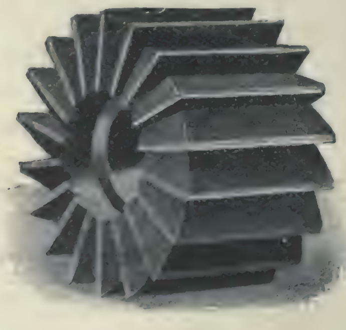


Fig. 134.
Cutter with coarse pitched straight teeth.

If cutters are considered only with reference to the form of their teeth, they may be distinguished by the following types:—

I. Cutters of the old type with fine pitched teeth, (figs.132 and 133).
II. Cutters of the new type with coarse pitched straight teeth, (fig. 134).
III. Cutters of the new type with coarse pitched spiral teeth, (fig. 135).
IV. Backed-off cutters with straight teeth, (fig. 136).
V. Backed-off cutters with spiral teeth, (fig. 137).

Small cutters, as illustrated in figs. 138 and 139, are used for cutting the teeth of fine pitched cutters as per type I.

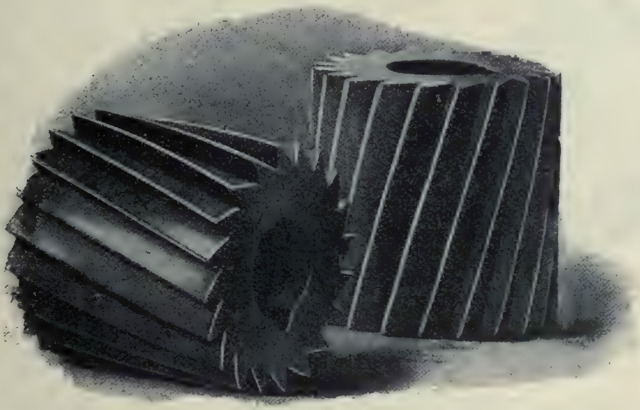


Fig. 135.
Cutters with coarse pitched spiral teeth.

Cutting the straight teeth of a coarse pitched cutter as per type II is one of the simplest operations with regard to the cutting of teeth. They are cut with a cutter as shown in figs. 140 and 141, and can be turned out on a plain milling machine with plain index centres.

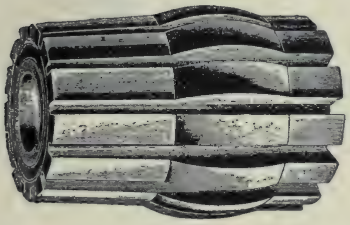


Fig. 136.
Backed-off cutter with straight teeth.

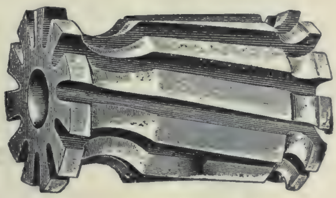


Fig. 137.
Backed-off cutter with spiral teeth.

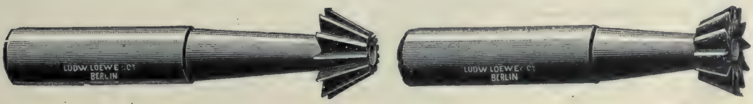


Fig. 138—139.
Small cutters for cutting fine pitched teeth.

This cutter is also used for cutting teeth on front faces (fig. 142).

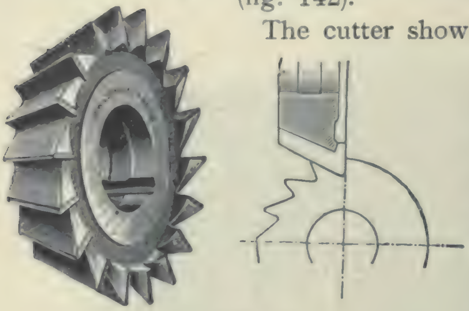


Fig. 140—141.
Cutters for milling straight coarse teeth.

The cutter shown in fig. 140 with one cutting edge square on the axis of the cutter is unsuited for cutting spiral teeth mentioned under type III, as, owing to the rotating movement of the cutter blank, the cutting edge would not have free play over the cutter so that the cutting rake would be sloped. For this reason a cutter similar to that shown in fig. 143 is employed with both cutting edges at an angle to the axis. As has already been stated on pages 59 and 60, the larger angle is generally fixed at 40⁰, the smaller one varying from 12⁰ to 20⁰. The axis of the cutter-blank must also be placed at an angle to the milling table and that for the following reason, viz:—to prevent the teeth acquiring another form to that given by the operating cutter. This becomes much more involved:

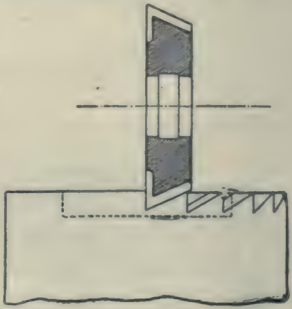


Fig. 142.
Cutting the end teeth.

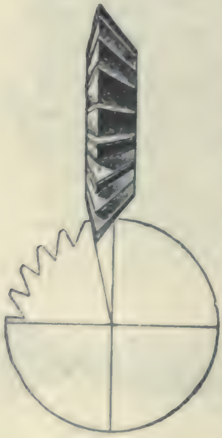


Fig. 143.
Cutter for milling spiral teeth.

1⁰. The cutter to be milled must be placed at an angle, (fig. 144).

2⁰. It must be fed on in a straight line.

3⁰. It has to revolve on its own axis during the feed.

The operating cutter must be placed in such a position to the blank that the cutting plane of the smallest angle passes exactly through the centre of the cutter to be milled, (fig. 143), or, as it occasionally happens when a sharper cutting edge than 90^0 is desired, the tangent of the cutting plane of the sharpest angle is allowed to fall slightly at the side of the centre. (fig. 145). According as the larger angle of the cutter is to the right or left, and the rotating movement of the blank a right or left hand cutter is obtained.

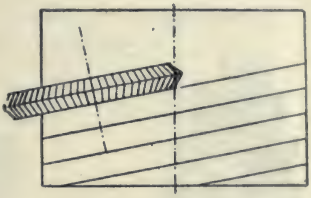


Fig. 144.
Position of the cutter and blank when cutting spiral teeth.

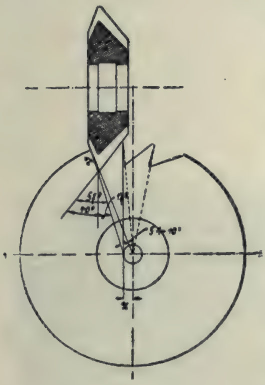


Fig. 145.
Position of operating cutter to the blank.

Of the backed-off cutters those referred to under type IV with straight teeth are the most general. If the cutters mentioned under types I—III obtain their definite form after the teeth have been cut, this is not so in the case of backed-off cutters. As a matter of fact, it cannot in this case be correctly said that the teeth are cut; a number of grooves are cut with a cutter as illustrated in figs. 146 and 147 which serve not only to allow the chips to escape but also as an outlet for the tool which will form the teeth; the cutter and the backing-off tool together form the teeth in this case, since the cutter which milled the grooves, forms the front plane of the backed-off teeth.

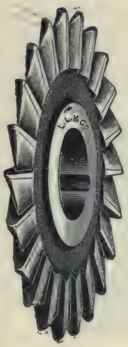


Fig. 146.

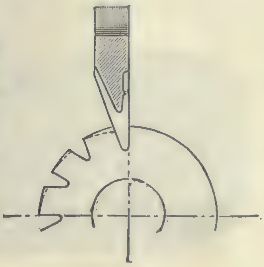


Fig. 147.

Cutter for backed-off mills with straight teeth.

The backed-off cutter with spiral teeth, type V, undergoes precisely the same treatment as that with straight teeth. The difference in treatment between the backed-off cutter with straight teeth and that with spiral teeth is just the same as exists between ordinary coarse pitched cutters with straight or spiral teeth. As is the case with the last named cutters, another cutter is also necessary for milling the front planes, (figs. 148 and 149).

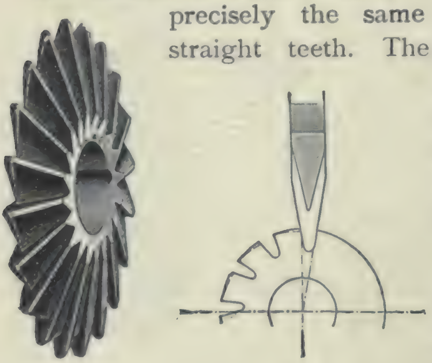


Fig. 148. Fig. 149.
Cutter for backed-off mills with spiral teeth.

In principle the two pairs of cutters display the same difference; the treatment of the backed-off cutter with spiral teeth is considerably more complicated than is the case with the cutter with straight teeth.

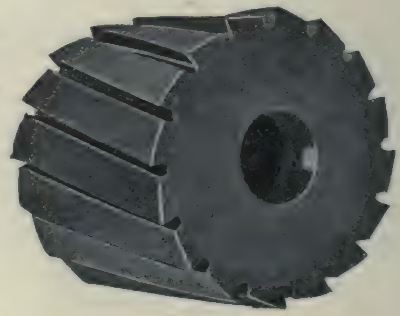


Fig. 150.
Plain milling cutter.

Figs. 150 and 151 represent a type of cutter which, considering the form of the teeth, could be reckoned among the backed-off cutters mentioned in types IV and V, but which, considering the manufacture, belongs to those referred to in types II and III, the teeth being milled entirely by the cutter on the milling machine.

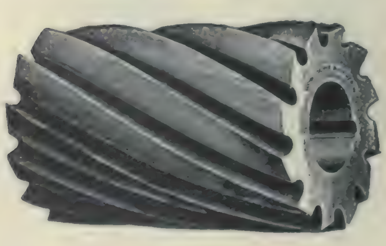


Fig. 151.
Plain milling cutter.

Fig. 150 represents a cutter with a flat tooth back, fig. 151 one with a tooth back similar to that obtained on the backing-off lathe.

The cutters shown in figs. 146 to 149 are also employed for milling the spiral and straight grooves in this type of cutter. However, with this kind of cutter spiral teeth are almost exclusively used, being intended for heavy work, whilst, at the same time, it is exclusively made as a plain milling cutter, (figs. 150 and 151).

Figs. 152 and 153 shows a cutter and the manner in which it is employed for milling flat teeth figs. 154 and 155 that for milling teeth having the form of backed-off teeth.

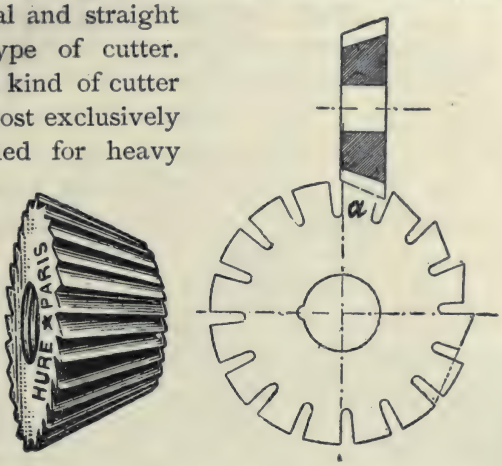


Fig. 152. Fig. 153.
Cutter for milling flat teeth.

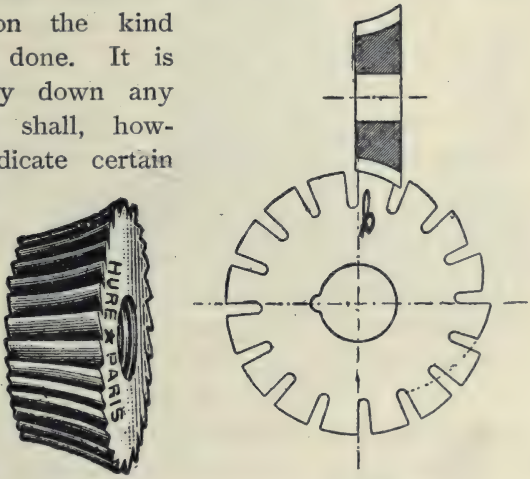


Fig. 154. Fig. 155.
Cutter for milling round teeth.

The question as to whether backed-off cutters or those with ordinary teeth shall be used depends on the kind of work to be done. It is impossible to lay down any fast rule. We shall, however, try to indicate certain points which will show which sort is most advantageous in certain cases.

The backed-off cutter is the generally employed type for profile milling in its most varied form: it has almost entirely superseded the old type formed cutter with a fine pitch of teeth, though this latter is still occasionally met with. Formed cutters with ordinary coarse pitched teeth are not made, unless the profile is composed of a combination of straight lines or is very simple.

The backed-off cutter preserves its tooth form unaltered until it is entirely worn out, an advantage of great importance in the case of articles manufactured in large quantities.

The teeth of backed-off cutters are much stronger and possess greater resistance than those of the ordinary milled type.

Owing to the stronger form of the teeth, the backed-off formed cutter may be given a considerably higher degree hardness without fear of the teeth breaking off, consequently they need less sharpening.

Backed-off cutters last very much longer than those with ordinary milled teeth as there is much more material on the teeth so that more re-sharpening is possible. When re-sharpening the backed-off cutter, the space for the chips is increased, whereas in the other type it becomes smaller.

The re-sharpening of backed-off cutters, which is only done on the cutting plane, and not on the back of the teeth, is quickly and easily carried out, with the other type this is more difficult.

Plain cutters for milling straight surfaces such as face cutters, end mills and angle cutters, the cutter with coarse pitched teeth have held their own against the backed-off cutter and have, of late, been much more used than was the case some years ago, especially for work requiring great accuracy.

More and better work can be obtained on the smaller and lighter-built milling machines by using a cutter with a pitch of teeth which is not too coarse than with a backed-off cutter, as, with the same cutting speed and feed, more teeth are cutting at the same time, because the backed-off cutter works with far fewer teeth and must, with the same feed, cut away a much thicker chip. The ordinary cutter is almost exclusively employed for working bronze and brass on account of the softness of the metal.

What has here been said with reference to backed-off cutters does not apply altogether to milled-off cutters.

After we have successively considered with which cutters the various types of cutters are milled, we shall proceed to consider the process of teeth milling.

b. MILLING THE TEETH.

I. *The fine pitched cutter.*

a. With straight lines or composed of straight and circular lines.

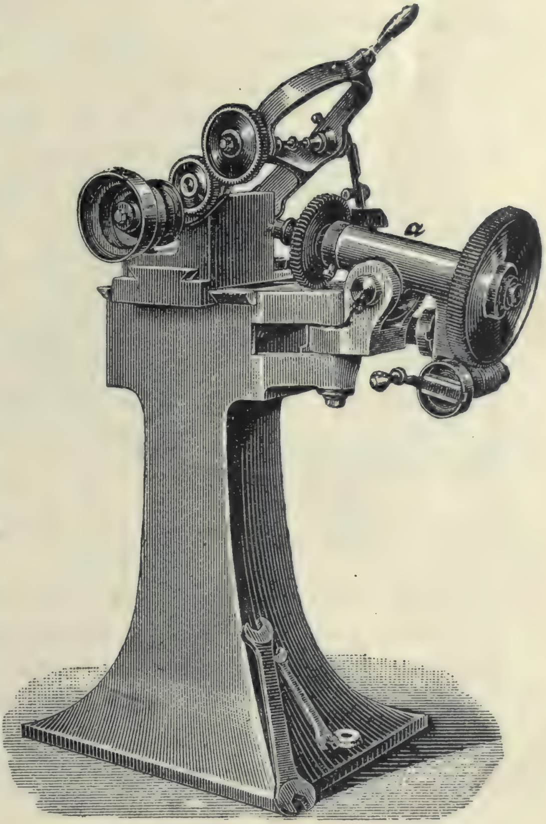


Fig. 156.
Machine formerly in use for milling the teeth of fine pitched cutters.

Fig. 156 represents one of the first milling machines for the manufacture of cutters.

The cutter that is filed by hand is of very small diameter, and mounted on a small arbor which forms part of the spindle itself.

A pinion at the rear of the cone pulley meshes in an idle wheel which imparts movement to the wheel mounted on the main spindle which rotates in the left hand side arm of the fork which is provided with a hub for carrying the spindle. The end of this spindle is provided with a conical bore for fixing the arbor. One end of the little cutter arbor is tapered with a slot, at the other end it is provided with a centre. The tapered end of the arbor is fixed in the spindle bore (fig. 157), whilst the other end has an end thrust bearing. The cutter blank is placed on the top of the spindle rotating in the sleeve indicated in fig. 156 with *a*. This sleeve, and with it the spindle, can swivel round the pin *p* at an angle of 90° from vertical to horizontal; for cutting teeth on the circumference, the sleeve *a* is set vertically. A worm and worm wheel are to be seen at the end of the spindle, with which the division is accomplished as follows:—

The wormwheel has for instance 180 teeth. The worm is single.

Each turn of the handle which is fastened on the wormshaft causes the spindle to move $^1/_{180}$th of a revolution or 2°.

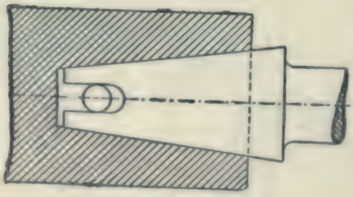


Fig. 157.
Fixing the arbor in the spindle.

The handle, and with it the worm, is locked in the notch of the disc which is provided with 4 notches at 90°, and as the handle can be turned exactly $^1/_2$ or $^1/_4$ revolution, the wormshaft consequently also makes a half or a quarter revolution, equal to $1^0 = {^1/_{360}}$ or $30' = {^1/_{720}}$ revolution. In this way a different number of teeth can be cut, though always a multiple or fraction of the number of teeth of the wormwheel (this should be a wormwheel but was formerly simply a spur wheel).

The number of divisions obtainable was amply sufficient for the earlier fine pitched cutters.

The approximate number of teeth of the cutter is first decided upon according to the diameter of the cutter and the thickness of the teeth, after which the number obtainable which approaches most closely to that is taken and from this the exact thickness of the teeth can be fixed.

1st example.

A cutter with a diameter of 4 inches is to be provided with teeth of about $^1/_8{}''$; consequently $\frac{3.14 \times 4}{^1/_8}$ = about 104 teeth must be cut.

The numbers most closely approximating hereto are either 90 or 120; if 90 be chosen, the thickness of the teeth will be $\frac{12.56}{90} = 0.14$ inch. No: of turns of the handle $\frac{180}{90} = 2$.

2nd example.

A cutter having a diameter of $1^1/_2$ inch is to be provided with teeth of about $^3/_{32}$ inch; consequently $\frac{3.14 \times 1^1/_2}{^3/_{32}} =$ about 50 teeth must be cut.

The numbers most closely approximating hereto are either 45 or 50; if 45 teeth be taken, the thickness of the teeth will be $\frac{4.71}{45} = 0.1$ inch. No: of turns of the handle, $\frac{180}{45} = 4$.

3rd example.

A cutter having a diameter of 1 inch is to be provided with teeth of about $^1/_{12}{}''$ inch, consequently $\frac{3.14 \times 1}{^1/_{12}} =$ about 36 teeth must be cut.

It being possible to cut exactly 36 teeth, the thickness of the teeth will accordingly be $\frac{3.14}{36} = 0.09$ inches. No: of turns of the handle, $\frac{180}{36} = 5$.

4th example.

A cutter having a diameter of $5^3/_8$ inch is to be provided with teeth of about $^1/_8$ inch; consequently, $\frac{3.14 \times 5^3/_8}{^1/_8} =$ about 143 teeth must be cut.

The nearest number is 144. The thickness of the teeth will accordingly be $^1/_8$ inch. No: of turns of the handle, $\frac{180}{144} = 1\frac{1}{4}$.

The foregoing examples hold good provided the worm-wheel has 180 teeth. It is self-evident that the calculation depends upon and must be in conformity with the number of teeth of the wheel in question.

The slide which carries the fork with the little arbor can be adjusted in accordance to the diameter of the cutter blank.

We have now explained how the cutter is driven, how the cutter blank is mounted and how the division is obtained.

When the slide has set the working cutter at the exact depth and the machine has been set in motion, the handle of the fork visible in the illustration, is taken in the hand. The fork swivels on the same centre as the cone pulley. If then, the stud which supports the fork as seen in the illustration is removed, the latter falls by its own weight. The fork has however, in the meantime been taken in the hand, the working cutter is allowed to descend on the cutterblank and the milling of the teeth is commenced. According as the metal is cut away, the weight of the fork causes the working cutter to go farther. The workman must now feel with his hand to what extent he must bear the weight of the fork or can allow it to continue uninterruptedly or must even increase the pressure, according as it is necessary to cut more or less coarse teeth.

Up to about 15 years ago cutters were still manufactured on the Continent in the manner described, later on one of the arms of the fork on this machine was lengthened and provided with an adjustable counterweight so as to obtain the desired pressure and the feed may now be said to be more or less automatic. In any case, the pressure with which the working cutter was forced through the metal could now be regulated and was not entirely dependent on the hand of the workman which was very uncertain owing to the hand becoming tired so quickly so that the fork was held first with the right hand, then with the left and vice versa. Moreover, the workman's hands were now free to brush away the fine chips from the teeth of the working cutter which otherwise clogged it up and destroyed it.

Seeing that the working cutter describes an arch, the teeth cut will also be arched, being deeper in the middle of the cutter than at the edges, (figs. 158 and 159), so that the tooth will have to be filed straight after being milled by hand.

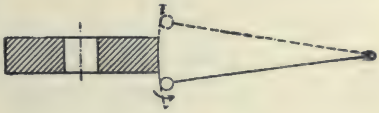


Fig. 158.
Course of milling cutter.

These machines were also employed for milling gear wheel cutters similar to those shown in figs. 132 and 133, The teeth were first milled on the circumference and as this line is very short, the arch was not very much out of the straight and the back was finished off subsequently without much trouble.

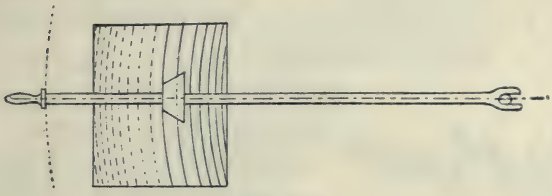


Fig. 159.
Course of milling cutter.

The flanks are given a circular form, the spindle being placed horizontally, sometimes a little slanting and a cutter is used, the diameter of which is equal to double the radius which is desired for the flank of the cutter.

The stop is set in a desired position so that the cutter always works to the same point, the sharp edges being afterwards rounded-off with the file. (figs. 160 and 161).

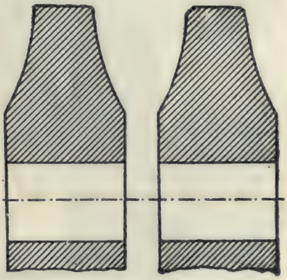


Fig. 160 and 161.
Rounding-of the teeth.

The development of the milling machines has first and foremost led to the correct cutting of gear wheels, though formerly people were satisfied with gear wheels milled with such imperfect cutters.

The machine described above was built at the time by Oerlikon.

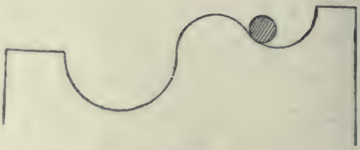


Fig. 162.
Milling a formed cutter with fine pitched teeth.

The foregoing may safely be regarded as history, though striking testimony is afforded to the progress made by milling machines when this machine is compared with the universal milling machine of the present day, about which we have so far purposely kept silent, but which is certainly known to every reader, and it is known that the machine described above was in use on the continent even as late as 1890 in large establishments and that in 1893 Knabbe described it as "a compact and neatly constructed machine."

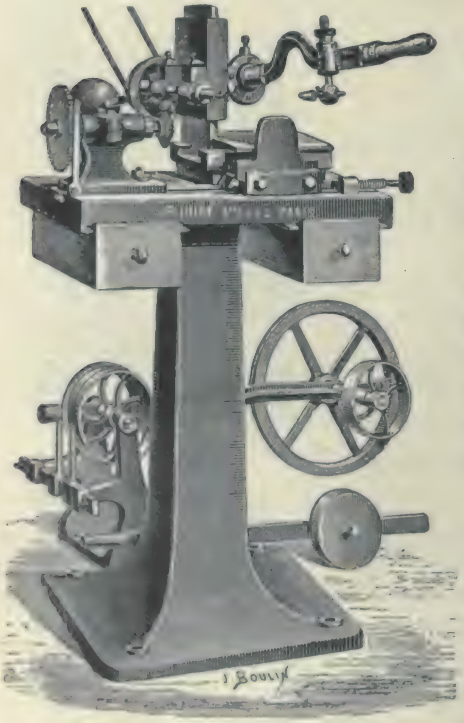


Fig. 163.
Profile milling machine by Huré.

b. Formed cutters with fine pitch of teeth.

The machine shown in fig. 156 is unsuitable for the manufacture of formed cutters.

It is necessary as far as the working cutter is concerned that the diameter should always be smaller than twice the smallest radius of the profile. (See fig. 162).

The desired form is obtained by a combination of a horizontal and vertical motion.

Fig. 163 represents profile milling a machine manufactured by Huré. The cutter blank is mounted on the arbor whilst the working cutter has to complete three motions, viz:—rotary, horizontal and vertical. A cam is fixed on the table, (in the illustration tooth-shaped). A lever, that controls the movement of the vertical slide, is provided with a hardened steel roll which pushes against the cam. A counterweight attached to the other end of the lever raises the vertical slide so that the lever must be continuously pressed down against the cam by hand. If the pressure ceases, the lever, and with it the working cutter, immediately rises. The horizontal feed of the vertical slide with the cutter is automatic. The division of the teeth is provided for by means of a simple notched disc into which a plunger is pressed by means of a spring. The cam is an enlarged copy of the profile of the cutter so that any possible irregularities or imperfections are communicated but slightly to the cutter.

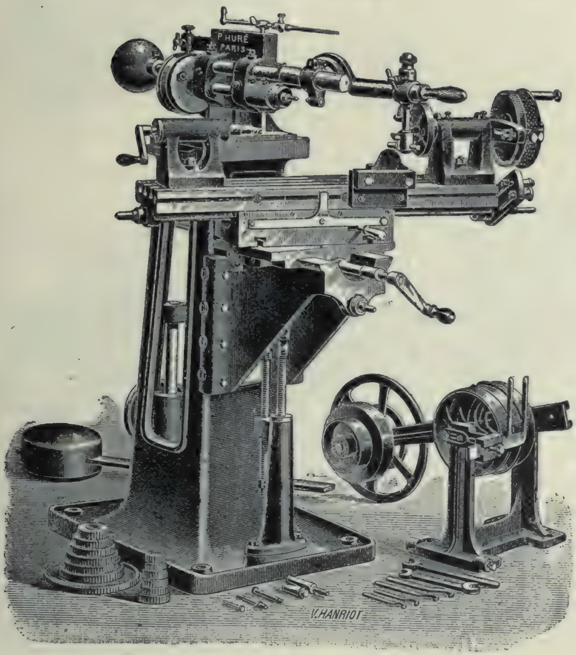


Fig. 164.
Profile milling machine by Huré.

Huré has since reconstructed this machine as shown in fig. 164.

The workpiece has now automatic horizontal feed so that only a vertical movement is imparted to the working cutter. Formed cutters of greater width can now be taken between the centres. The table can be set at an angle, has transverse movement and is vertically adjustable, whilst the dividing head permits of the cutters being given different numbers of teeth. Although redesigned the principle of this machine is similar to that shown in fig. 163. For so far as formed cutters with fine pitched teeth are still used, (not backed-off), this is one of the current types.

As a sign of the application of the different types of cutters, it may be mentioned that this type of milling machine is no longer constructed by makers of milling machines in the United States, England and Germany, though the machines represented in figs. 163 and 164 have been included in Huré's latest catalogue, from which one may gather that although the backed-off formed cutter has entirely superseded the cutter with fine teeth in the United States, England and Germany, the latter are still in use in France so that there is still a demand for the machines mentioned above.

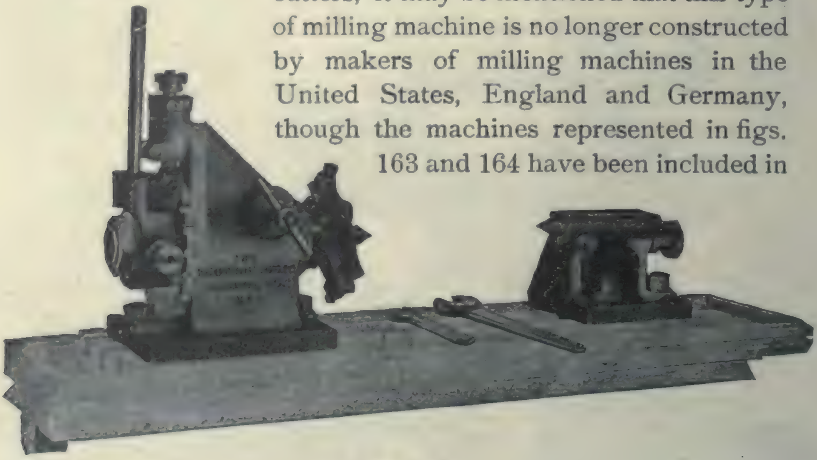


Fig. 165.
Plain index centers.

II. *Cutters with coarse pitched straight teeth.*

The milling of cutters with straight teeth is of a simple nature. They can be made on every plain milling machine by simply mounting on the table the attachment shown in fig. 165.

For a different number of teeth, dials with a corresponding number of holes must be used. As, however, these cutters can be milled just as well on the universal milling

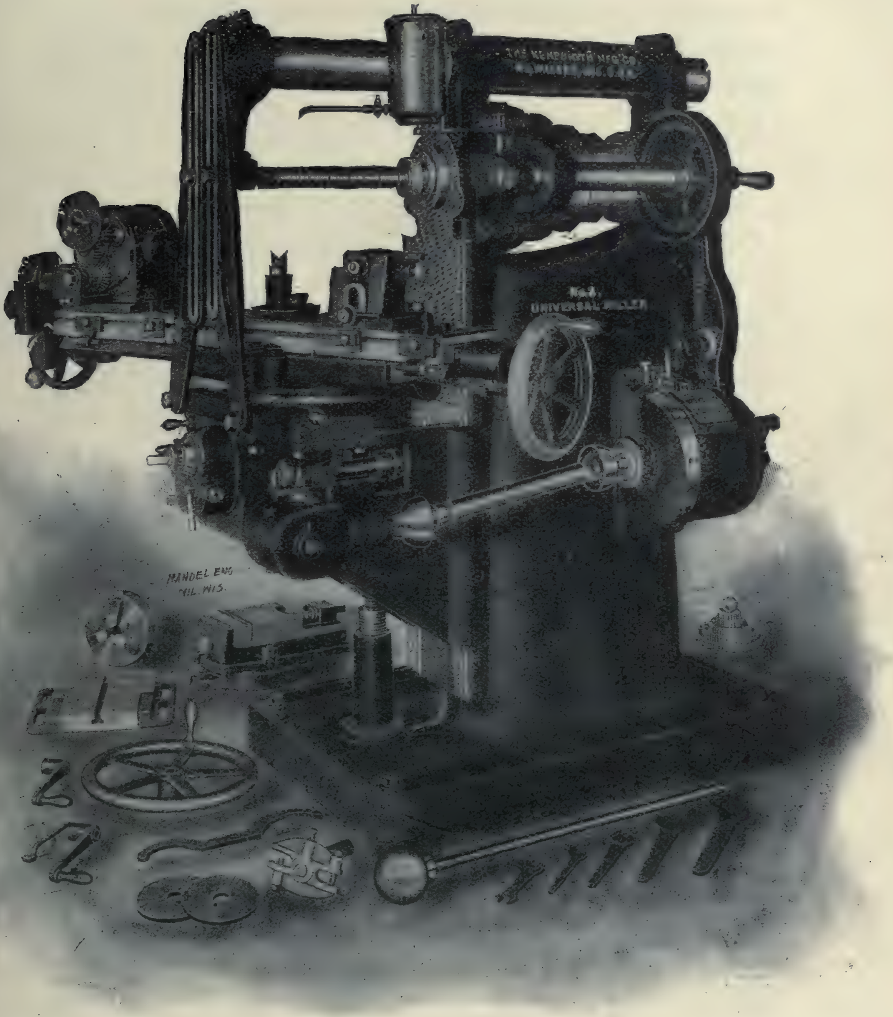


Fig. 166. Universal milling machine.

machine and the description of the manufacture of cutters with spiral teeth practically includes those with straight teeth, we shall not go now into details with reference to these cutters in order to avoid unnecessary repetition or a premature description of the manufacture of spiral cutters but shall now proceed to describe the manner of milling cutters with spiral teeth.

III. *Cutters with coarse pitched spiral teeth.*

The milling of cutters with spiral teeth is performed on a machine, the general type of which is shown in fig. 166.

But few skilled workmen really understand the theory of the universal dividing head and those who really do understand it most times guard their knowledge even more jealously than is the case with the knowledge of thread cutting on the lathe; moreover, for so many the difficulty exists that they have no opportunity of becoming practically acquainted with the universal milling machine and its different operations and further it is impossible to explain it in a few words. Furthermore, to understand the universal dividing head aright, more than a mere superficial knowledge of mathematics is requisite than is generally possible for a workman to acquire. It so often happens that workmen are able to use the machine, but only with the assistance of the tables appurtaining to the machine; and it is just those who are obliged to use the machine with the assistance of the tables, who will be glad to know how the figures given therein are arrived at, so that for the future they can use the tables for their convenience without being any longer entirely dependent on them.

It is not intended in this chapter to treat of the complete universal milling machine with all its accessories but solely *the universal dividing head with its index and worm wheel mechanism.*

c. DIVIDING HEADS.

The dividing head on the milling machine serves to divide the circumference of a circle into a number of equal parts.

Dividing heads may be separated into three classes.

a. Plain index centres by which only a very limited number of divisions can be obtained for milling three, four, six, eight or more sides.

b. Dividing heads by which all divisions are possible by means of *index plates*, the rotary movement being communicated to the workpiece by means of a worm and worm wheel.

c. Dividing heads by which all divisions are possible by means of *gear wheels* which transmit the rotary movement of the worm and worm wheel to the workpiece.

Plain index centres, such as those mentioned under *a*, have already been shown in fig. 165. The cutter blank or workpiece is taken between the centres, the spindle rotating in the headstock at the rear of which a dial is mounted, the circumference of which is provided with notches at regular intervals.

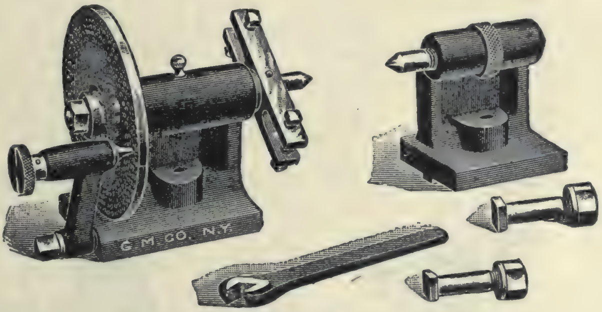


Fig. 167.
Plain index centres.

A plunger at the top of the headstock above the dial is pressed into the notches by means of a spring and so locks the spindle. It is evident that divisions can be made and the circle can only be divided into as many equal parts as there are notches in the dial and as the factors of the number of notches. If the dial, for instance, is divided into 24 parts, the following divisions can be obtained, viz:—24, 12, 8, 6, 4, 3 and 2.

Fig. 167 shows a similar set of index centres, arranged however, for further divisions, though in this construction also the index plate is placed direct on the spindle. The dial is provided with a different number of holes on circles of various diameters. A tapered plunger inserted in the holes by a spring locks the spindle while cutting. This plunger can be set at the various circles. As a large number of holes can be drilled in the plate and each circle has a different number of divisions, this permits of a considerable number of divisions being obtained.

If, for instance, one of the circles is divided into 120 divisions, this number can be resolved into the following factors, viz:—

2, 2, 2, 3, and 5,

so that the following divisions can thus be obtained by this circle alone:—

2
3
2 × 2 = 4
5
2 × 3 = 6
2 × 2 × 2 = 8
2 × 5 = 10
2 × 2 × 3 = 12
3 × 5 = 15
2 × 2 × 5 = 20
2 × 2 × 2 × 3 = 24
2 × 3 × 5 = 30
2 × 2 × 2 × 5 = 40
2 × 2 × 3 × 5 = 60
and 120

Although with this number of holes fairly consecutive divisions can be obtained up to 15, the subsequent divisions are rather far between, until finally there are no intermediate divisions possible between 60 and 120. Fig. 168 shows a set of index centres similar to the foregoing, the only difference being that the circumference of the disc is provided with teeth in which a worm engages so that it is no longer necessary to turn the disc by hand with the possibility of turning slightly too far or making mistakes but the disc is regularly adjusted by turning the handle. If, for instance, this disc has 7 different circles of holes

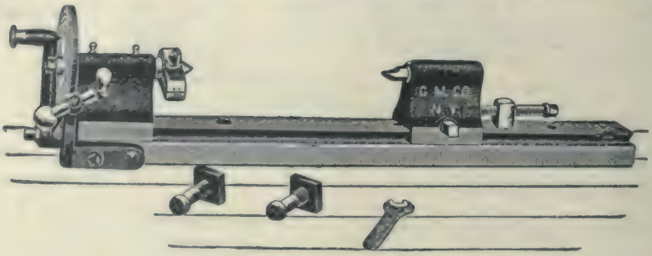


Fig. 168.
Plain index centres, rotary movement imparted to the spindle by worm wheel.

containing the following divisions, viz:—44, 48, 56, 60, 72, 84, 96, then in addition to these divisions the following can also be obtained, viz:—

$44 = 2 \times 2 \times 11$ therefore 2.
$2 \times 2 = 4$.
$2 \times 11 = 22$.
$48 = 2 \times 2 \times 2 \times 2 \times 3$ therefore 3.
$2 \times 3 = 6$.
$2 \times 2 \times 2 = 8$.
$2 \times 2 \times 3 = 12$.
$2 \times 2 \times 2 \times 2 = 16$.
$2 \times 2 \times 2 \times 3 = 24$.
$56 = 2 \times 2 \times 2 \times 7$ therefore 7.
$2 \times 7 = 14$.
$2 \times 2 \times 7 = 28$.
$60 = 2 \times 2 \times 3 \times 5$ therefore 5.
$2 \times 5 = 10$.
$3 \times 5 = 15$.
$2 \times 2 \times 5 = 20$.
$2 \times 3 \times 5 = 30$.
$72 = 2 \times 2 \times 2 \times 3 \times 3$ therefore
$3 \times 3 = 9$.
$2 \times 3 \times 3 = 18$.
$2 \times 2 \times 3 \times 3 = 36$.
$84 = 2 \times 2 \times 3 \times 7$ therefore
$3 \times 7 = 21$.
$2 \times 3 \times 7 = 42$.
$96 = 2 \times 2 \times 2 \times 2 \times 2 \times 3$ therefore
$2 \times 2 \times 2 \times 2 \times 2 = 32$.
$2 \times 2 \times 2 \times 2 \times 3 = 48$.

The following progressive chain of divisions can consequently be obtained with these centres, viz:—2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 18, 20, 21, 22, 24, 28, 30, 32, 36, 42, 44, 48, 56, 60, 72, 84, 96.

The same peculiarity is here noticeable as in the previous case, namely, that in the higher division no intermediate divisions are obtainable.

Figs. 169 and 170 represent an indexing head of the class referred to under *b*. The principal difference is at once to be seen from the illustration; the index plate in this case is not mounted directly on the spindle but on a worm which is in gear with a worm wheel mounted on the spindle. With the first mentioned index centres the dial rotates and the plunger is fixed, in the head as shown in fig. 169 and 170 the plunger revolves and the index plate is fixed. If, in the case of the index centres mentioned under *a* the spindle completes one revolution for one complete turn of the index plate, in the dividing head mentioned under *b*, the spindle only completes a small part of a revolution for one complete turn of the crankhandle, that part of a revolution being equivalent to the number of teeth in the worm wheel, always supposing the worm to have a single thread.

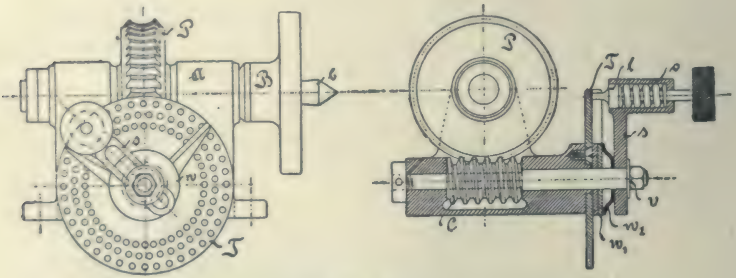


Fig. 169 and 170.
Dividing head without means for setting the spindle in an angle.

The worm wheel P is mounted on the hollow spindle B carried in A, the nose of this spindle is threaded so as to take a chuck. The worm C is in gear with this worm wheel, the worm is turned by the crankhandle *s* in which housing *o* a plunger with tapered pin is placed. Centered on the worm shaft but fixed to the casting is the index plate T against which the sector w^1 is pressed by the flat spring w^2. This sector rotates on the worm shaft. The end of the plunger *l* is provided with a knurled head by which the crankhandle is turned. By means of the slot in the handle, the plunger in the housing can be set at any circle.

This dividing head is, however, unsuitable for spiral milling; for this purpose a set of gear wheels between the worm shaft and the spindle which effects the longitudinal motion of the milling table on which the dividing head is placed, must effect the rotary movement of the dividing head spindle.

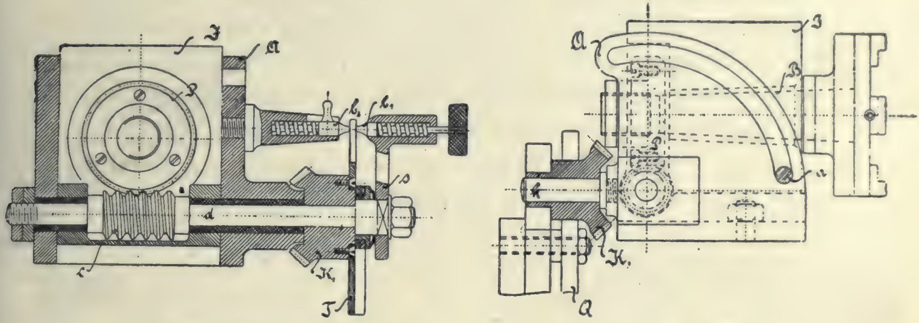


Fig. 171. Fig. 172.

Universal dividing head.

Figs. 171 and 172 illustrate a universal dividing head constructed in this manner.

The housing J which swivels round the worm shaft *d* carries the spindle B and is affixed to the external casting A and can be set in any angle from a few degrees below the horizontal to a few degrees over the perpendicular. On the spindle B is placed the worm wheel P. As this worm wheel together with the housing J revolves on the wormshaft *d*, the worm will remain in mesh whatever may be the position of the worm wheel, whether the spindle B is slanting or perfectly vertical. The worm wheel P is wedged and adjustable for wear in order to prevent play, (fig. 173). The bolts *a* in the circular

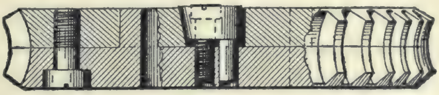


Fig. 173.

Wedged worm wheel.

slot of the casting A serve to connect the housing J to the external casting, whilst the angle at which I is set can be read from a graduated scale.

This dividing head is adapted for spiral milling. The spiral line is produced whenever the dividing head spindle and with it the workpiece rotates slowly during the longitudinal motion of the table and, consequently of the workpiece. Two motions are thus imparted to the cutter, viz:—a rectilinear and a rotary, so that it is evident that the pitch of the spiral is dependent on the relative proportion of these two motions.

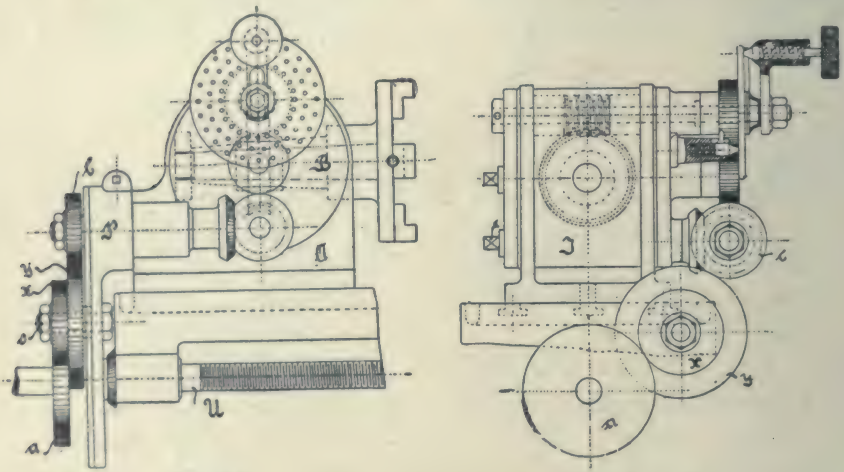


Fig. 174. Fig. 175.

Kempsmith universal dividing head.

For this purpose a bevel gear K is connected to the index plate T, which runs loose on the worm shaft *d*. This gear is meshed by another bevel gear K_2, (fig. 172), which rotates on a stud K in the casting A. The set of bevel gears K and K_2 are driven by change gears, one of which is mounted on the hub of the bevel gear K_2, another on the feed screw which gives the longitudinal motion to the table, one or two intermediate gears being mounted on a stud at the side of the dividing head. It is by means of these gears that the spiral line is produced.

Figs. 174 and 175 represent a Kempsmith dividing head.

In the interior of the closed head are the worm and worm wheel which are thus protected from dirt and chips which might otherwise fall in. The worm wheel lies in one line with the centre-line of the swivelling part of the head the worm runs on top of the worm wheel. Between the bevel gears and the worm there is still another gear wheel that transmits the movement of the bevel gears to the worm.

To the third category of dividing heads referred to under *c* belongs the Reinecker dividing head of German construction shown in figs. 176—178.

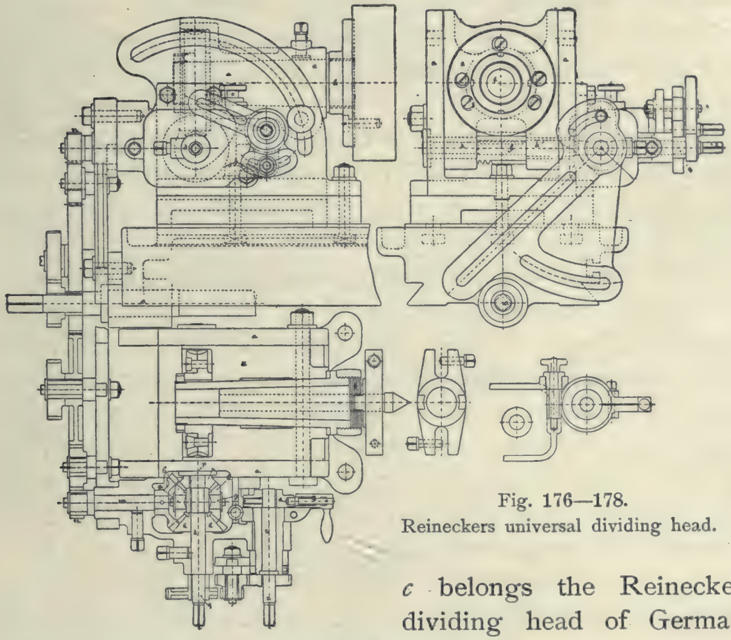


Fig. 176—178.
Reineckers universal dividing head.

In this dividing head the index plate is done away with, the divisions as also the spiralline being obtained by gear wheels.

The change gears for the divisions are to be calculated so that a complete revolution of the crankhandle is necessary for each further division.

The housing *a* which can be set at any angle from horizontal to the perpendicular in which the spindle *b* revolves in the external casting *a*. On the spindle *b* is the worm wheel *e* which is meshed by the worm *f*. The bevel gear K, (fig. 177), is set on the worm shaft outside the casting *a*. Behind this is fixed at *d* a cross head at the studs *g*. *g*, of which are two idle bevel gears, *h*. *h*. which mesh in K. These gears mesh another bevel gear *i* which is mounted on a loose bush rotating on the wormshaft. A change gear *g* mounted on this same bush *p*, which is caused to rotate by one or two intermediate gears by means of the gear wheel fixed on the spindle *r*. On the spindle *r* is the index plate *s* which is provided with only one hole into which the taper pin *t* is pushed.

The change gears which transmit the motion of the spindle *r* to the bush *p* are calculated in accordance with the number of divisions.

The transmission from the spindle *r* to the spindle *b* is effected as follows:—The motion of the spindle *r* is transmitted by the bush *p* to the gear wheels, the small bevel gear *i* rotating at the same time as it is also mounted on the bush *p* and as the two small bevel gears *h*. *h*. mesh in *i*, these are also caused to rotate. The bevel gears *h*. *h*. mesh in the bevel gear *k*. The gear *h* can, however, rotate on the wormshaft, so that they run over the bevel gear *k*, making a double rotation, viz.:—on their own spindle and also on the wormshaft *d*. As, however, the cross head on which they are fixed, is keyed to the wormshaft *d*, they must both rotate together, the spindle *b* being also moved by the worm and worm wheel.

The rotating motion of the dividing head spindle for the milling of spirals is effected as follows:—The wheel on the feed screw *o* of the milling table causes the spindle *m* to rotate by means of intermediate gears, and at the extremity of this spindle is the bevel gear *l* which rotates *k*; *k* rotates the two small bevel gears *h*. *h*. on their own centre line and as they revolve over the bevel gear *i*, they also rotate on the wormshaft and since the cross head is connected with these bevel gears and is keyed to the wormshaft, it is caused to rotate, the worm wheel *e* and the spindle *b* being rotated by the wormshaft *d*.

Opposite the dividing head is the tailstock which is illustrated in fig. 165.

Dividing heads, especially those belonging to class *b*, are made in various styles.

d. INDEXING WITH THE INDEX PLATE.

In the dividing heads described under *b* and *c* the worm wheel is fixed on the spindle. As a result, if the spindle makes one complete revolution, the worm wheel must, ipse facto, do the same. If the worm wheel has 60 teeth and the worm is single-threaded then, for each revolution of the worm wheel, i. e. the spindle, the worm must make 60 revolutions.

If it is desired to divide the circumference into two parts, each 180°, the worm wheel must make half a revolution and the worm $\frac{60}{2} = 30$ revolutions; for three divisions the worm wheel must make $\frac{1}{3}$ of a revolution and the worm $\frac{60}{3} = 20$ revolutions;

for 4 divisions, the worm wheel make $\frac{1}{4}$ revolution, the worm $\frac{60}{4} = 15$ revs.;

for 6 divisions, $\frac{60}{6} = 10$ revolutions;

for 10 divisions, $\frac{60}{10} = 6$ revolutions;

for 12 divisions, $\frac{60}{12} = 5$ revolutions, etc.

Examples.

1) The worm wheel on the spindle has 100 teeth; a cutter with 20 teeth must be cut. The worm is single-threaded. The worm must, therefore, make $\frac{100}{20} = 5$ revolutions for each division.

If the worm is double-threaded, then, for each revolution the worm wheel will be moved over *two* teeth. A worm wheel with 60 teeth will, consequently, have completed one full revolution, when the worm has made $\frac{60}{2} = 30$ revolutions.

If the worm is treble-threaded, 3 teeth of the worm wheel will be turned over for each revolution of the worm, and will thus have completed one revolution only after $\frac{60}{3} = 20$ revolutions of the worm.

2) The worm wheel on the spindle has 100 teeth. The worm is double-threaded. 25 teeth are to be milled on the cutter.

In this case the worm must make $\frac{100}{2 \times 25} = 2$ revolutions for each division.

3) The worm wheel on the spindle has 60 teeth. The worm is treble-threaded. 20 teeth are to be milled on the cutter.

The worm must consequently make $\frac{60}{3 \times 20} = 1$ revolution for each division.

The foregoing may be expressed in the following formula:—

The number of teeth on the worm wheel divided by the product of the number of threads of the worm and the number of divisions to be made is equal to the number of revolutions of the worm required for one division.

In order to allow of all divisions being obtained within certain limits, the index plate on the universal dividing head is provided with a different number of divisions, each of which is placed separately in a different circle, the number of divisions being indicated for each circle (fig. 179).

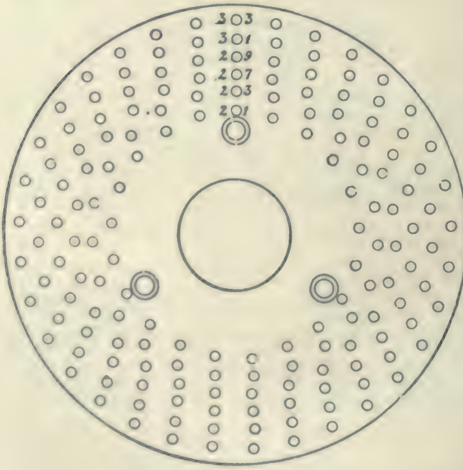


Fig. 179. Index plate.

Given that:—

t = No: of teeth of worm wheel.

g = No: of threads of worm.

o = No: of revolutions of the worm necessary for one complete revolution of the worm wheel.

v = No: of divisions.

n = No: of revolutions of the worm necessary for one division.

it follows that:—

(1) $\frac{t}{g} = o.$ (2) $o \cdot g = t.$ and (3) $\frac{t}{o} = g.$

further

(4) $\frac{t}{g \cdot v} = n.$ (5) $\frac{t}{g \cdot n} = v.$ (6) $v \cdot n \cdot g = t.$

and as

$\frac{t}{g} = o.$ (7) $\frac{o}{v} = n.$ and (8) $v \cdot n = o.$

It should be noted that $g =$ No: of *threads* of the worm does *not* refer to the pitch but to the worm being single, double or treble-threaded.

A few examples, based upon the foregoing formulas, will now be given.

$$t = 80. \qquad g = 2.$$

Required. The number of revolutions of the worm necessary for one complete revolution of the spindle.

$$o = \frac{t}{g} = \frac{80}{2} = 40 \text{ revolutions.}$$

The worm is treble-threaded. The worm wheel completes one revolution in 30 revolutions of the worm.

Required. The number of teeth on the worm wheel.

$$g = 3 \,.\, o = 30 \,.\, t \text{ is required.}$$
$$t = 3 \times 30 = 90 \text{ teeth.}$$

$$o = 40 \,.\, t = 120 \,.\, g \text{ is required.}$$
$$g = \frac{t}{o} = \frac{120}{40} = 3. \text{ worm is treble-threaded.}$$

The number of teeth on the worm wheel is 100. The worm is double-threaded. The number of teeth on the cutter is 25. How many revolutions must the worm make for one division?

$$t = 100, \quad g = 2, \quad v = 25, \quad n \text{ is required.}$$

$$n = \frac{t}{g \cdot v} = \frac{100}{2 \times 25} = 2 \text{ revolutions.}$$

The number of teeth on the worm wheel is 120. The worm is treble-threaded. The worm makes two revolutions for each division. How many teeth will be milled on the cutter?

$$t = 120, \quad g = 3, \quad n = 2, \quad v \text{ is required.}$$

$$v = \frac{t}{g \cdot n} = \frac{120}{3 \times 2} = 20 \text{ teeth.}$$

So far, cases have only been taken in which the revolution of the worm has consisted of whole numbers, so that really one hole in the index plate would suffice.

It is evident that n is not always a whole number, in fact, it is seldom that this is the case.

The following examples will now be given in succession:—

$$t = 40, \quad g = 2, \quad v = 40, \quad n \text{ is thus } \frac{40}{2 \times 40} = \tfrac{1}{2} \text{ revolution.}$$

$$t = 40, \quad g = 2, \quad v = 80, \quad n \text{ is thus } \frac{40}{2 \times 80} = \tfrac{1}{4} \text{ revolution.}$$

$$t = 40, \quad g = 2, \quad v = 160, \quad n \text{ is thus } \frac{40}{2 \times 160} = \tfrac{1}{8} \text{ revolution.}$$

For these divisions the index plate must be made use of and a circle chosen which is divided into a number divisible by 8.

On a circle containing, for instance, 56 holes, the crank-

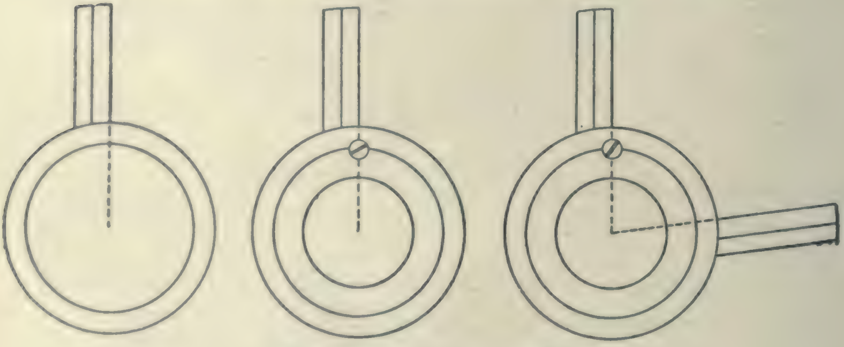


Fig. 180—182. Dividing sector.

handle must turn over 28 in the first of the examples given above, 14 in the second and 7 in the third.

In addition to being much too troublesome, it would too frequently give rise to errors and mistakes, if it were necessary to have to count these holes every time and so, in order to simplify matters, the sector to be seen in fig. 183 has been introduced on the index plate. The legs of this sector, which are clearly shown in figs. 180—182, can be placed at any desired angle. If, for instance, in the last of the examples given above, the crank were to pass over 7 holes, the sector would be so set that it would take in one hole more seeing that the locking pin itself already occupies one hole.

The circle over which the locking pin must move is not always a proper fraction of a revolution. This is very seldom the case, as most times it proves to be an improper fraction. To take the following example :

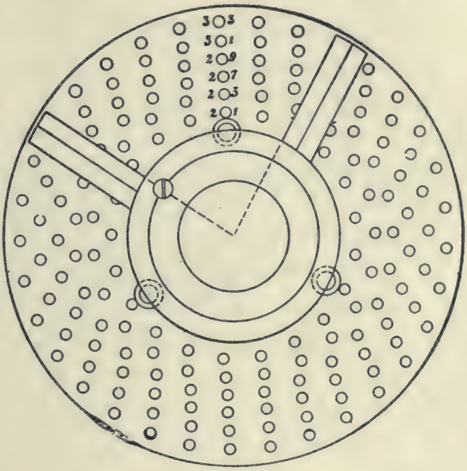


Fig. 183.
Index plate with dividing sector.

The worm wheel has 80 teeth. The worm is double-threaded.

No: of teeth on the cutter 32.

$$n = \frac{g \cdot v}{t} = \frac{80}{2 \times 32} = \frac{80}{64} = 1 + \frac{16}{64} = 1 + \frac{1}{4}.$$

Further, given that:—

$h =$ No: of complete turns of the crankhandle.
$q =$ No: of holes enclosed by the sector minus 1.
$p =$ No: of holes of the circle.

it follows that $n = h + \frac{q}{p}$.

Example.

$$t = 100, \quad g = 2, \quad v = 40.$$

$$o = \frac{g}{t} = \frac{100}{2} = 50.$$

$$n = \frac{o}{v} = \frac{50}{40}.$$

$$n = h + \frac{q}{p} = 1\frac{10}{40}.$$

So that:—

1st. The crankhandle must make one complete turn.

2nd. The crankhandle must make $\frac{10}{40}$ turn.

Consequently the sector must be set so that on a circle with 40 holes, it encloses $10 + 1 = 11$ holes.

The numerator and denominator of a fraction can be either divided or multiplied by the same number, to be used as occasion requires.

If, in the foregoing case, there is no circle with 40 holes but only one with 80, then $\frac{20}{80}$ can be employed and the sector must enclose 21 holes; if there be no circle with 40 holes, but one with 56, then $\frac{14}{56}$ can be taken, the sector enclosing 15 holes on a circle with 56.

It is advisable to prove the calculation before proceeding to work.

According to (8) $v \,.\, n = o$, or according to (6) $v \,.\, n \,.\, g = t$. *The number of divisions multiplied by the no: of turns of the crankhandle is equal to the no: of turns of the crankhandle necessary for one complete revolution of the wormwheel or to the no: of teeth on the wormwheel divided by the no: of threads of the worm.*

Taking the foregoing example, we get:—

$v \,.\, n = o = 32 \times 1\frac{1}{4} = 40 =$ no: of turns of the crankhandle for one complete revolution, or $v \,.\, n \,.\, g = t = 32 \times 1\frac{1}{4} \times 2 = t = 80$.

A number of examples will now be given.

(1) No: of teeth on wormwheel $t = 60$.

Worm is double-threaded so that $g = 2$.

No: of teeth on cutter $v = 35$.

$$\text{Therefore, } o = \frac{t}{g} = \frac{60}{2} = 30.$$

$$n = \frac{o}{v} = \frac{30}{35}.$$

On the circle with 35 holes, the crankhandle must be moved over 30 holes for each division.

Proof: $v \,.\, g \,.\, n = t = 35 \times 2 \times \frac{30}{35} = t = 60$ teeth.

(2) $t = 80, \quad g = 2, \quad v = 30.$

$$o = \frac{t}{g} = 40.$$

$$n = \frac{o}{v} = \frac{40}{30}.$$

$$n = h + \frac{q}{p} = 1\frac{10}{30}.$$

The cranckhandle must make one complete turn plus 10 holes on a circle with 30 holes.

Proof: $v \,.\, g \,.\, n = t. \quad 30 \times 2 \times 1\tfrac{1}{3} = 80.$

(3) $t = 120. \quad g = 3. \quad v = 88$

$$o = \frac{t}{g} \times 40.$$

$$n = \frac{o}{v} = \frac{40}{88}.$$

(4) $t = 120. \quad g = 3. \quad v = 23.$

$$o = \frac{t}{g} = 40.$$

$$n = \frac{o}{v} = \frac{40}{23}.$$

$$n = h + \frac{q}{p} = 1\frac{17}{23} \text{ or } 1\frac{34}{46} \text{ or } 1\frac{68}{92}.$$

$$v \,.\, g \,.\, n = t = 23 \times 3 \times 1\frac{17}{23} = 120.$$

(5) A reamer with 5 grooves is to be cut on the milling machine.

$t = 60. \quad g = 1. \quad v = 5.$

$o = t = 60.$

$$n = \frac{o}{v} = \frac{60}{5} = 12.$$

For each division the crankhandle must thus complete 12 turns.

It is evident that the same difficulty is to be met with here as in counting up the holes on the circle, viz:—that the workman can easily make a mistake. As a matter of fact, it is a much more serious matter here than in the previous case, as the workman could recount if he had made a mistake or were interrupted, or he could mark the hole in advance in which the locking pin should come, but in this case the workman has to turn the crankhandle, so that, if interrupted or he loses count, the only thing to be done in order to be correct is to turn back to the groove which has been milled and recommence counting.

In order to do away with these difficulties, a mechanism is to be found on some dividing heads which permits of rapid indexing by turning the spindle by hand. The worm can be thrown out of gear with its wormwheel.

The divisions on the index plates which are usually to be found with universal milling machines are 15, 17, 19, 20, 21, 22, 23, 27, 29, 31, 32, 33, 37, 39, 41, 43, 47 and 49, usually on three index plates.

Tables giving the No: of turns which the crankhandle must complete for different divisions.

$v =$ No: of divisions, $p =$ division-circle, $h + \frac{q}{p} =$ No: of turns which the crankhandle must complete on the division-circle indicated by p.

Table IX.

Table in which the value of $o = 40$.

$$\text{Suitable for } \left\{\begin{array}{ll} t = 40. & g = 1. \\ t = 80. & g = 2. \\ t = 120. & g = 3. \end{array}\right.$$

v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$
2	—	20	26	39	$1^{21}/_{39}$	50	20	$^{16}/_{20}$	90	27	$^{12}/_{27}$	152	19	$^{5}/_{19}$
3	39	$13^{21}/_{39}$	27	27	$1^{13}/_{27}$	52	39	$^{30}/_{39}$	92	23	$^{10}/_{23}$	155	31	$^{8}/_{31}$
4	—	10	28	49	$1^{21}/_{49}$	54	27	$^{20}/_{27}$	94	47	$^{20}/_{47}$	156	39	$^{10}/_{39}$
5	—	8	29	29	$1^{11}/_{29}$	55	33	$^{24}/_{33}$	95	19	$^{8}/_{19}$	160	20	$^{5}/_{20}$
6	39	$6^{26}/_{39}$	30	39	$1^{13}/_{39}$	56	49	$^{35}/_{49}$	96	24	$^{10}/_{24}$	164	41	$^{10}/_{41}$
7	49	$5^{35}/_{49}$	31	31	$1^{9}/_{31}$	58	29	$^{20}/_{29}$	98	49	$^{20}/_{49}$	165	33	$^{8}/_{33}$
8	—	5	32	20	$1^{5}/_{20}$	60	39	$^{26}/_{39}$	100	20	$^{8}/_{20}$	168	21	$^{5}/_{21}$
9	27	$4^{12}/_{27}$	33	33	$1^{7}/_{33}$	62	31	$^{20}/_{31}$	104	39	$^{15}/_{39}$	170	17	$^{4}/_{17}$
10	—	4	34	17	$1^{3}/_{17}$	64	16	$^{10}/_{16}$	108	27	$^{10}/_{27}$	172	43	$^{10}/_{43}$
11	33	$3^{21}/_{33}$	35	49	$1^{7}/_{49}$	65	39	$^{24}/_{39}$	110	33	$^{12}/_{33}$	180	27	$^{6}/_{27}$
12	39	$3^{13}/_{39}$	36	27	$1^{3}/_{27}$	66	33	$^{20}/_{33}$	115	23	$^{8}/_{23}$	184	23	$^{5}/_{23}$
13	39	$3^{3}/_{39}$	37	37	$1^{3}/_{37}$	68	17	$^{10}/_{17}$	116	29	$^{10}/_{29}$	185	37	$^{8}/_{37}$
14	49	$2^{42}/_{49}$	38	19	$1^{1}/_{19}$	70	49	$^{28}/_{49}$	120	39	$^{13}/_{39}$	188	47	$^{10}/_{47}$
15	39	$2^{26}/_{39}$	39	39	$1^{1}/_{39}$	72	27	$^{15}/_{27}$	124	31	$^{10}/_{31}$	190	19	$^{4}/_{19}$
16	20	$2^{10}/_{20}$	40	—	1	74	37	$^{20}/_{37}$	128	16	$^{5}/_{16}$	195	39	$^{8}/_{39}$
17	17	$2^{6}/_{17}$	41	41	$^{40}/_{41}$	75	15	$^{8}/_{15}$	130	39	$^{12}/_{39}$	196	49	$^{10}/_{49}$
18	27	$2^{6}/_{27}$	42	21	$^{25}/_{21}$	76	19	$^{10}/_{19}$	132	33	$^{10}/_{33}$	200	20	$^{4}/_{20}$
19	19	$2^{2}/_{19}$	43	43	$^{40}/_{43}$	78	39	$^{20}/_{39}$	135	27	$^{8}/_{27}$	210	21	$^{4}/_{21}$
20	—	2	44	33	$^{30}/_{33}$	80	20	$^{10}/_{20}$	136	17	$^{5}/_{17}$	220	33	$^{6}/_{33}$
21	21	$1^{19}/_{21}$	45	27	$^{24}/_{27}$	82	41	$^{20}/_{41}$	140	49	$^{14}/_{49}$	230	23	$^{4}/_{23}$
22	33	$1^{27}/_{33}$	46	23	$^{20}/_{23}$	84	21	$^{10}/_{21}$	144	18	$^{5}/_{18}$	240	18	$^{3}/_{18}$
23	23	$1^{17}/_{23}$	47	47	$^{40}/_{47}$	85	17	$^{8}/_{17}$	145	29	$^{8}/_{29}$	248	31	$^{5}/_{31}$
24	39	$1^{26}/_{39}$	48	18	$^{15}/_{18}$	86	43	$^{20}/_{43}$	148	37	$^{10}/_{37}$	280	49	$^{7}/_{49}$
25	20	$1^{12}/_{20}$	49	49	$^{40}/_{49}$	88	33	$^{15}/_{33}$	150	15	$^{4}/_{15}$	300	15	$^{2}/_{15}$

Table X.

$o=60$. Suitable for $t=60$. $g=1$. $t=120$. $g=2$. $t=180$. $g=3$.

v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$
2	—	30	37	37	$1^{23}/_{37}$	80	20	$^{15}/_{20}$	138	23	$^{10}/_{23}$	235	47	$^{12}/_{47}$
3	—	20	38	19	$1^{11}/_{19}$	81	27	$^{20}/_{27}$	140	21	$^{9}/_{21}$	240	20	$^{5}/_{20}$
4	—	15	39	39	$1^{21}/_{39}$	82	41	$^{30}/_{41}$	144	24	$^{10}/_{24}$	245	49	$^{12}/_{49}$
5	—	12	40	20	$1^{10}/_{20}$	84	21	$^{15}/_{21}$	145	29	$^{12}/_{29}$	260	39	$^{9}/_{39}$
6	—	10	41	41	$1^{19}/_{41}$	85	17	$^{12}/_{17}$	147	49	$^{20}/_{49}$	264	44	$^{10}/_{44}$
7	21	$8^{12}/_{21}$	42	21	$1^{9}/_{21}$	86	43	$^{30}/_{43}$	148	37	$^{15}/_{37}$	270	27	$^{6}/_{27}$
8	24	$7^{12}/_{12}$	43	43	$1^{17}/_{43}$	87	29	$^{20}/_{29}$	150	20	$^{8}/_{20}$	276	23	$^{5}/_{23}$
9	27	$6^{18}/_{27}$	44	33	$1^{12}/_{33}$	88	22	$^{15}/_{22}$	155	31	$^{12}/_{31}$	280	14	$^{3}/_{14}$
10	—	6	45	83	$1^{11}/_{33}$	90	39	$^{26}/_{39}$	156	26	$^{10}/_{26}$	290	29	$^{6}/_{29}$
11	33	$5^{15}/_{33}$	46	23	$1^{7}/_{23}$	92	23	$^{15}/_{23}$	158	79	$^{30}/_{79}$	300	20	$^{4}/_{20}$
12	—	5	47	47	$1^{13}/_{47}$	93	31	$^{20}/_{31}$	160	16	$^{6}/_{16}$	310	31	$^{6}/_{31}$
13	39	$4^{24}/_{29}$	48	20	$1^{5}/_{20}$	94	47	$^{30}/_{47}$	164	41	$^{15}/_{41}$	320	16	$^{3}/_{16}$
14	21	$4^{6}/_{21}$	49	49	$1^{11}/_{49}$	95	19	$^{12}/_{19}$	165	33	$^{12}/_{33}$	330	33	$^{6}/_{33}$
15	—	4	50	20	$1^{4}/_{20}$	96	16	$^{10}/_{16}$	170	17	$^{6}/_{17}$	340	17	$^{3}/_{17}$
16	20	$3^{15}/_{20}$	51	17	$1^{3}/_{17}$	98	49	$^{30}/_{49}$	172	43	$^{15}/_{43}$	345	23	$^{4}/_{23}$
17	17	$3^{9}/_{17}$	52	39	$1^{6}/_{39}$	99	33	$^{20}/_{33}$	174	29	$^{10}/_{29}$	360	18	$^{3}/_{18}$
18	39	$3^{13}/_{39}$	54	27	$1^{3}/_{27}$	100	20	$^{12}/_{20}$	180	18	$^{6}/_{18}$	370	37	$^{6}/_{37}$
19	19	$3^{3}/_{19}$	55	33	$1^{3}/_{33}$	102	17	$^{10}/_{17}$	185	37	$^{12}/_{37}$	372	31	$^{5}/_{31}$
20	—	3	56	28	$1^{2}/_{28}$	104	26	$^{15}/_{26}$	188	47	$^{15}/_{47}$	380	19	$^{3}/_{19}$
21	21	$2^{18}/_{21}$	57	19	$1^{1}/_{19}$	105	21	$^{12}/_{21}$	190	19	$^{6}/_{19}$	390	39	$^{6}/_{39}$
22	33	$2^{24}/_{33}$	58	29	$1^{1}/_{29}$	108	27	$^{15}/_{27}$	192	16	$^{5}/_{16}$	400	20	$^{3}/_{20}$
23	23	$2^{14}/_{23}$	60	—	1	110	33	$^{15}/_{33}$	195	39	$^{12}/_{39}$	410	41	$^{6}/_{41}$
24	20	$2^{10}/_{10}$	62	31	$^{30}/_{31}$	111	37	$^{20}/_{37}$	196	49	$^{15}/_{49}$	420	21	$^{3}/_{21}$
25	20	$2^{8}/_{20}$	63	21	$^{20}/_{21}$	114	19	$^{10}/_{19}$	200	20	$^{6}/_{20}$	430	43	$^{6}/_{43}$
26	39	$2^{12}/_{39}$	64	16	$^{15}/_{16}$	115	23	$^{12}/_{23}$	204	17	$^{5}/_{17}$	440	22	$^{3}/_{22}$
27	27	$2^{6}/_{27}$	65	39	$^{36}/_{39}$	116	29	$^{15}/_{29}$	205	41	$^{12}/_{41}$	450	15	$^{2}/_{15}$
28	21	$2^{3}/_{21}$	66	33	$^{30}/_{33}$	117	39	$^{10}/_{39}$	210	21	$^{6}/_{21}$	460	23	$^{3}/_{23}$
29	29	$2^{2}/_{29}$	68	17	$^{15}/_{17}$	120	20	$^{10}/_{20}$	215	43	$^{12}/_{43}$	470	47	$^{6}/_{47}$
30	—	2	69	23	$^{20}/_{23}$	123	41	$^{20}/_{41}$	216	18	$^{5}/_{18}$	480	16	$^{2}/_{16}$
31	31	$1^{29}/_{31}$	70	21	$^{18}/_{21}$	124	31	$^{15}/_{31}$	220	33	$^{9}/_{33}$	510	17	$^{2}/_{17}$
32	24	$1^{21}/_{24}$	72	18	$^{15}/_{18}$	126	21	$^{10}/_{21}$	222	37	$^{10}/_{37}$	540	27	$^{3}/_{27}$
33	33	$1^{27}/_{33}$	74	37	$^{30}/_{37}$	129	43	$^{20}/_{43}$	225	15	$^{4}/_{15}$	900	20	$^{2}/_{20}$
34	17	$1^{13}/_{17}$	75	20	$^{16}/_{20}$	130	39	$^{18}/_{39}$	228	19	$^{5}/_{19}$			
35	21	$1^{15}/_{21}$	76	19	$^{15}/_{19}$	132	33	$^{15}/_{33}$	230	23	$^{6}/_{23}$			
36	39	$1^{26}/_{39}$	78	39	$^{30}/_{39}$	135	18	$^{8}/_{18}$	234	39	$^{10}/_{39}$			

Table XI.

$o = 80$. Suitable for $t = 80$. $g = 1$. $t = 160$. $g = 2$. $t = 240$. $g = 3$.

v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$
2	—	40	37	37	$2^{6}/_{37}$	86	43	$^{40}/_{43}$	176	33	$^{15}/_{33}$	320	16	$^{4}/_{16}$
3	39	$26^{26}/_{39}$	38	19	$2^{2}/_{19}$	88	33	$^{30}/_{33}$	180	18	$^{8}/_{18}$	328	41	$^{10}/_{41}$
4	—	20	39	39	$2^{2}/_{39}$	90	27	$^{24}/_{27}$	184	23	$^{10}/_{23}$	330	33	$^{8}/_{33}$
5	—	16	40	—	2	92	23	$^{20}/_{23}$	185	37	$^{16}/_{37}$	336	21	$^{3}/_{21}$
6	39	$13^{13}/_{39}$	41	41	$1^{39}/_{41}$	94	47	$^{40}/_{47}$	188	47	$^{20}/_{47}$	340	17	$^{4}/_{17}$
7	21	$11^{9}/_{21}$	42	21	$1^{19}/_{21}$	96	18	$^{15}/_{18}$	190	19	$^{8}/_{19}$	344	43	$^{10}/_{34}$
8	—	10	43	43	$1^{37}/_{43}$	98	49	$^{40}/_{49}$	195	39	$^{16}/_{39}$	360	18	$^{4}/_{18}$
9	18	$9^{16}/_{18}$	44	33	$1^{27}/_{33}$	100	20	$^{16}/_{20}$	196	49	$^{20}/_{49}$	368	23	$^{5}/_{23}$
10	—	8	45	18	$1^{14}/_{18}$	104	39	$^{30}/_{39}$	200	20	$^{8}/_{20}$	370	37	$^{8}/_{37}$
11	33	$7^{9}/_{33}$	46	23	$1^{17}/_{23}$	105	21	$^{16}/_{21}$	205	41	$^{16}/_{41}$	376	47	$^{10}/_{17}$
12	18	$6^{12}/_{18}$	47	47	$1^{33}/_{47}$	108	27	$^{20}/_{27}$	208	39	$^{15}/_{39}$	380	19	$^{4}/_{19}$
13	39	$6^{6}/_{39}$	48	39	$1^{26}/_{39}$	110	33	$^{24}/_{33}$	210	21	$^{8}/_{21}$	390	39	$^{8}/_{39}$
14	21	$5^{15}/_{21}$	49	49	$1^{31}/_{49}$	112	21	$^{15}/_{21}$	215	43	$^{10}/_{43}$	400	20	$^{4}/_{20}$
15	15	$5^{5}/_{15}$	50	20	$1^{12}/_{20}$	115	23	$^{16}/_{23}$	216	27	$^{20}/_{27}$	410	41	$^{8}/_{41}$
16	—	5	52	39	$1^{21}/_{39}$	116	29	$^{20}/_{29}$	220	33	$^{12}/_{33}$	420	21	$^{4}/_{21}$
17	17	$4^{12}/_{17}$	54	27	$1^{13}/_{27}$	120	39	$^{26}/_{39}$	225	45	$^{16}/_{45}$	430	43	$^{8}/_{43}$
11	18	$4^{8}/_{18}$	55	33	$1^{15}/_{38}$	124	31	$^{30}/_{31}$	230	23	$^{8}/_{23}$	440	33	$^{6}/_{33}$
19	19	$4^{4}/_{19}$	56	21	$1^{9}/_{21}$	128	16	$^{10}/_{16}$	232	29	$^{10}/_{29}$	460	23	$^{4}/_{23}$
20	—	4	58	29	$1^{11}/_{29}$	130	39	$^{24}/_{39}$	235	47	$^{16}/_{47}$	470	47	$^{8}/_{47}$
21	21	$3^{17}/_{21}$	60	18	$1^{6}/_{18}$	132	33	$^{20}/_{33}$	240	18	$^{6}/_{48}$	480	18	$^{3}/_{18}$
22	33	$3^{21}/_{33}$	62	31	$1^{9}/_{31}$	135	27	$^{16}/_{27}$	245	49	$^{16}/_{49}$	490	49	$^{8}/_{49}$
23	23	$3^{11}/_{23}$	64	20	$1^{5}/_{20}$	136	17	$^{10}/_{17}$	248	31	$^{10}/_{31}$	500	25	$^{4}/_{25}$
24	39	$3^{13}/_{39}$	65	39	$1^{9}/_{39}$	140	21	$^{12}/_{21}$	250	25	$^{8}/_{25}$	510	39	$^{6}/_{39}$
25	20	$3^{4}/_{20}$	66	33	$1^{7}/_{33}$	144	27	$^{15}/_{27}$	256	16	$^{5}/_{16}$	540	27	$^{4}/_{27}$
26	39	$3^{3}/_{39}$	68	17	$1^{3}/_{17}$	145	29	$^{16}/_{29}$	260	39	$^{12}/_{39}$	560	21	$^{3}/_{21}$
27	27	$2^{26}/_{27}$	70	21	$1^{3}/_{21}$	148	37	$^{20}/_{37}$	270	27	$^{8}/_{27}$	580	29	$^{4}/_{29}$
28	21	$2^{18}/_{21}$	72	18	$1^{2}/_{18}$	150	15	$^{8}/_{15}$	272	17	$^{5}/_{17}$	600	15	$^{2}/_{15}$
29	29	$2^{22}/_{29}$	74	37	$1^{3}/_{37}$	152	19	$^{10}/_{19}$	280	21	$^{6}/_{21}$	620	31	$^{4}/_{31}$
30	39	$2^{26}/_{39}$	75	15	$1^{1}/_{15}$	155	31	$^{16}/_{31}$	288	18	$^{5}/_{18}$	640	16	$^{2}/_{16}$
31	31	$2^{18}/_{31}$	76	19	$1^{1}/_{19}$	156	39	$^{20}/_{39}$	290	29	$^{8}/_{29}$	660	33	$^{4}/_{33}$
32	20	$2^{10}/_{20}$	78	39	$1^{1}/_{39}$	160	16	$^{8}/_{16}$	296	37	$^{10}/_{37}$	680	17	$^{2}/_{17}$
33	33	$2^{14}/_{33}$	80	—	1	164	41	$^{20}/_{41}$	300	15	$^{4}/_{15}$	720	18	$^{2}/_{18}$
34	17	$2^{6}/_{17}$	82	41	$^{40}/_{41}$	168	21	$^{10}/_{21}$	304	19	$^{5}/_{19}$	800	20	$^{2}/_{20}$
35	21	$2^{6}/_{21}$	84	21	$^{20}/_{21}$	170	17	$^{8}/_{17}$	310	31	$^{8}/_{21}$			
36	18	$2^{4}/_{18}$	85	17	$^{16}/_{17}$	172	21	$^{20}/_{43}$	312	39	$^{10}/_{39}$			

Table XII.

$o = 120$. Suitable for $t = 120$. $g = 1$. $t = 240$. $g = 2$.

v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$
5	—	24	47	47	$2^{26}/_{47}$	90	39	$1^{13}/_{39}$	146	73	$^{60}/_{73}$	212	53	$^{30}/_{53}$	296	37	$^{15}/_{37}$
6	—	20	48	20	$2^{10}/_{20}$	92	23	$1^{7}/_{23}$	147	49	$^{40}/_{49}$	213	71	$^{40}/_{71}$	300	20	$^{8}/_{20}$
7	21	$17^{5}/_{21}$	49	49	$2^{22}/_{42}$	93	31	$1^{9}/_{31}$	148	37	$^{30}/_{37}$	215	43	$^{24}/_{43}$	305	61	$^{24}/_{61}$
8	—	15	50	20	$2^{8}/_{20}$	94	47	$1^{13}/_{47}$	150	20	$^{16}/_{20}$	216	27	$^{15}/_{27}$	308	77	$^{30}/_{77}$
9	18	$13^{6}/_{18}$	51	17	$2^{6}/_{17}$	95	19	$1^{5}/_{19}$	152	19	$^{16}/_{19}$	219	73	$^{40}/_{73}$	310	31	$^{12}/_{31}$
10	—	12	52	39	$2^{12}/_{39}$	96	20	$1^{5}/_{20}$	153	51	$^{40}/_{51}$	220	55	$^{30}/_{55}$	312	39	$^{15}/_{39}$
11	22	$10^{20}/_{22}$	53	53	$2^{14}/_{53}$	97	97	$1^{23}/_{97}$	154	77	$^{60}/_{77}$	222	37	$^{20}/_{37}$	315	21	$^{8}/_{21}$
12	—	10	54	27	$2^{6}/_{27}$	98	49	$1^{11}/_{49}$	155	31	$^{24}/_{31}$	225	15	$^{8}/_{15}$	318	53	$^{20}/_{53}$
13	39	$9^{9}/_{39}$	55	33	$2^{6}/_{33}$	99	33	$1^{7}/_{33}$	156	39	$^{30}/_{39}$	228	19	$^{10}/_{19}$	320	16	$^{6}/_{16}$
14	49	$8^{28}/_{49}$	56	49	$2^{7}/_{49}$	100	20	$1^{4}/_{20}$	158	79	$^{60}/_{79}$	230	23	$^{12}/_{23}$	328	41	$^{15}/_{41}$
15	—	0	57	19	$2^{2}/_{19}$	102	17	$1^{3}/_{17}$	159	53	$^{40}/_{53}$	231	77	$^{40}/_{77}$	330	33	$^{12}/_{33}$
16	20	$7^{10}/_{20}$	58	29	$2^{2}/_{29}$	104	39	$1^{6}/_{39}$	160	16	$^{12}/_{16}$	232	29	$^{15}/_{29}$	335	67	$^{24}/_{67}$
17	17	$7^{1}/_{17}$	59	59	$2^{2}/_{59}$	105	21	$1^{3}/_{28}$	162	27	$^{20}/_{27}$	234	39	$^{20}/_{39}$	340	17	$^{6}/_{17}$
18	39	$6^{26}/_{29}$	60	—	2	106	53	$1^{7}/_{33}$	164	41	$^{30}/_{41}$	235	47	$^{24}/_{17}$	344	43	$^{15}/_{43}$
19	19	$6^{6}/_{19}$	61	61	$1^{59}/_{61}$	108	27	$1^{3}/_{27}$	165	33	$^{24}/_{33}$	236	59	$^{30}/_{59}$	345	23	$^{8}/_{23}$
20	—	6	62	31	$1^{29}/_{31}$	110	33	$1^{3}/_{33}$	166	83	$^{60}/_{83}$	237	79	$^{40}/_{79}$	348	29	$^{10}/_{29}$
21	49	$5^{36}/_{49}$	63	21	$1^{19}/_{21}$	111	37	$1^{3}/_{37}$	168	21	$^{15}/_{21}$	240	20	$^{10}/_{20}$	350	35	$^{12}/_{35}$
22	33	$5^{15}/_{33}$	64	16	$1^{14}/_{16}$	112	28	$1^{2}/_{28}$	170	17	$^{12}/_{17}$	244	61	$^{30}/_{61}$	354	59	$^{20}/_{59}$
23	23	$5^{5}/_{23}$	65	39	$1^{33}/_{89}$	114	19	$1^{1}/_{19}$	172	43	$^{30}/_{43}$	245	49	$^{24}/_{49}$	360	18	$^{6}/_{18}$
24	—	5	66	33	$1^{27}/_{33}$	115	23	$1^{1}/_{23}$	175	35	$^{24}/_{35}$	246	41	$^{20}/_{41}$	370	37	$^{12}/_{37}$
25	20	$4^{16}/_{20}$	67	67	$1^{53}/_{67}$	116	29	$1^{1}/_{29}$	176	22	$^{15}/_{22}$	248	31	$^{15}/_{30}$	380	19	$^{6}/_{19}$
26	39	$4^{24}/_{39}$	68	17	$1^{13}/_{17}$	117	39	$1^{1}/_{39}$	177	59	$^{40}/_{59}$	250	25	$^{12}/_{25}$	390	39	$^{12}/_{39}$
27	27	$4^{12}/_{27}$	69	23	$1^{17}/_{23}$	118	59	$1^{1}/_{59}$	178	89	$^{60}/_{89}$	252	21	$^{10}/_{21}$	400	20	$^{6}/_{20}$
28	49	$4^{14}/_{49}$	70	49	$1^{35}/_{49}$	120	—	1	180	39	$^{26}/_{39}$	255	17	$^{8}/_{17}$	409	41	$^{12}/_{41}$
29	29	$4^{4}/_{29}$	71	71	$1^{49}/_{71}$	122	61	$^{60}/_{61}$	182	91	$^{60}/_{91}$	256	32	$^{15}/_{32}$	420	21	$^{6}/_{21}$
30	—	4	72	39	$1^{26}/_{39}$	124	31	$^{30}/_{31}$	183	61	$^{40}/_{81}$	258	43	$^{20}/_{43}$	430	43	$^{12}/_{43}$
31	31	$3^{27}/_{31}$	73	73	$1^{47}/_{73}$	125	25	$^{24}/_{25}$	184	23	$^{15}/_{23}$	260	13	$^{6}/_{10}$	440	22	$^{6}/_{22}$
32	20	$3^{15}/_{20}$	74	37	$1^{23}/_{27}$	126	21	$^{20}/_{21}$	185	37	$^{24}/_{37}$	264	33	$^{15}/_{33}$	450	15	$^{4}/_{15}$
33	33	$2^{21}/_{33}$	75	20	$1^{12}/_{20}$	127	127	$^{120}/_{127}$	186	31	$^{20}/_{31}$	265	53	$^{24}/_{53}$	460	23	$^{6}/_{23}$
34	17	$3^{9}/_{17}$	76	19	$1^{11}/_{19}$	128	16	$^{15}/_{16}$	188	47	$^{30}/_{47}$	267	89	$^{40}/_{89}$	470	47	$^{12}/_{47}$
35	49	$3^{21}/_{49}$	77	77	$1^{43}/_{77}$	129	43	$^{40}/_{43}$	190	19	$^{12}/_{19}$	268	67	$^{30}/_{67}$	480	20	$^{5}/_{20}$
36	33	$2^{11}/_{23}$	78	39	$1^{21}/_{39}$	130	39	$^{36}/_{39}$	192	16	$^{10}/_{16}$	270	27	$^{12}/_{27}$	490	49	$^{12}/_{49}$
37	37	$3^{9}/_{37}$	80	20	$1^{10}/_{20}$	132	33	$^{30}/_{33}$	195	39	$^{24}/_{39}$	276	23	$^{10}/_{23}$	500	25	$^{6}/_{25}$
38	19	$3^{3}/_{19}$	81	27	$1^{13}/_{27}$	134	67	$^{60}/_{67}$	196	49	$^{30}/_{49}$	280	49	$^{21}/_{49}$	510	17	$^{4}/_{17}$
39	39	$3^{3}/_{39}$	82	41	$1^{19}/_{41}$	135	27	$^{24}/_{27}$	198	33	$^{20}/_{33}$	282	47	$^{20}/_{47}$	520	39	$^{9}/_{39}$
40	—	3	83	83	$1^{37}/_{83}$	136	17	$^{15}/_{17}$	200	20	$^{12}/_{20}$	284	71	$^{30}/_{71}$	530	53	$^{12}/_{53}$
41	41	$2^{38}/_{41}$	84	49	$1^{21}/_{49}$	138	23	$^{20}/_{23}$	201	67	$^{40}/_{67}$	285	19	$^{8}/_{19}$	540	27	$^{6}/_{27}$
42	21	$2^{18}/_{21}$	85	17	$1^{7}/_{17}$	140	49	$^{42}/_{49}$	204	17	$^{10}/_{17}$	288	24	$^{10}/_{24}$	550	55	$^{12}/_{55}$
43	43	$2^{34}/_{43}$	86	43	$1^{17}/_{43}$	141	47	$^{40}/_{47}$	205	41	$^{24}/_{41}$	290	29	$^{12}/_{29}$	600	20	$^{4}/_{20}$
44	33	$2^{24}/_{33}$	87	29	$1^{11}/_{29}$	142	71	$^{60}/_{71}$	207	69	$^{40}/_{69}$	292	73	$^{30}/_{73}$	700	35	$^{6}/_{25}$
45	39	$2^{26}/_{39}$	88	33	$1^{12}/_{33}$	144	18	$^{15}/_{18}$	208	26	$^{15}/_{26}$	294	49	$^{20}/_{49}$	800	20	$^{3}/_{20}$
46	23	$2^{14}/_{23}$	89	89	$1^{31}/_{89}$	145	29	$^{24}/_{29}$	210	49	$^{28}/_{49}$	295	59	$^{24}/_{59}$	900	15	$^{2}/_{15}$
															1000	25	$^{3}/_{25}$

Table XIII.

$o=180$. Suitable for $t=180$. $g=1$. $t=360$. $g=2$.

v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$	v	p	$h+\frac{q}{p}$
10	—	18	49	49	$3^{35}/_{49}$	88	22	$2^{1}/_{22}$	141	47	$1^{13}/_{47}$	200	20	$^{18}/_{20}$	294	49	$^{30}/_{49}$
12	33	$16^{12}/_{33}$	50	20	$3^{12}/_{20}$	89	89	$2^{2}/_{89}$	142	71	$1^{19}/_{71}$	204	17	$^{15}/_{17}$	300	20	$^{12}/_{20}$
12	—	15	51	17	$3^{9}/_{17}$	90	—	2	144	20	$1^{5}/_{20}$	205	41	$^{36}/_{41}$	305	61	$^{36}/_{61}$
13	39	$13^{33}/_{39}$	52	39	$3^{18}/_{39}$	92	23	$1^{22}/_{23}$	145	29	$1^{7}/_{29}$	207	23	$^{20}/_{23}$	310	31	$^{18}/_{31}$
14	49	$12^{42}/_{49}$	53	53	$3^{21}/_{53}$	93	31	$1^{29}/_{31}$	146	73	$1^{17}/_{73}$	210	21	$^{18}/_{21}$	315	49	$^{28}/_{49}$
15	—	12	54	27	$3^{9}/_{27}$	94	47	$1^{43}/_{47}$	147	49	$1^{11}/_{49}$	212	53	$^{45}/_{53}$	320	32	$^{18}/_{32}$
16	16	$11^{4}/_{16}$	55	33	$3^{9}/_{33}$	95	19	$1^{17}/_{19}$	148	37	$1^{8}/_{37}$	215	43	$^{36}/_{43}$	330	33	$^{18}/_{33}$
17	17	$10^{10}/_{17}$	56	28	$3^{6}/_{28}$	96	16	$1^{14}/_{16}$	150	20	$1^{4}/_{20}$	216	48	$^{40}/_{48}$	335	67	$^{36}/_{67}$
18	—	10	57	19	$3^{3}/_{19}$	98	49	$1^{41}/_{49}$	152	38	$1^{7}/_{38}$	220	44	$^{36}/_{44}$	340	34	$^{18}/_{34}$
19	19	$9^{9}/_{19}$	58	29	$3^{3}/_{29}$	99	33	$1^{27}/_{33}$	153	51	$1^{9}/_{51}$	222	37	$^{30}/_{37}$	350	35	$^{18}/_{35}$
20	—	9	59	59	$3^{3}/_{59}$	100	20	$1^{10}/_{20}$	154	77	$1^{13}/_{77}$	225	20	$^{16}/_{20}$	360	20	$^{10}/_{20}$
21	49	$8^{28}/_{49}$	60	—	3	102	17	$1^{13}/_{17}$	156	39	$1^{6}/_{39}$	228	38	$^{30}/_{38}$	370	37	$^{18}/_{37}$
22	33	$8^{6}/_{33}$	61	61	$2^{58}/_{61}$	104	26	$1^{19}/_{26}$	158	79	$1^{11}/_{79}$	230	46	$^{36}/_{46}$	375	25	$^{12}/_{25}$
23	23	$7^{19}/_{23}$	62	31	$2^{28}/_{31}$	105	49	$1^{35}/_{49}$	160	32	$1^{4}/_{32}$	231	77	$^{60}/_{77}$	380	38	$^{18}/_{38}$
24	20	$7^{10}/_{20}$	63	21	$2^{18}/_{21}$	106	53	$1^{37}/_{53}$	162	27	$1^{3}/_{27}$	234	39	$^{30}/_{39}$	390	39	$^{18}/_{39}$
25	20	$7^{4}/_{20}$	64	16	$2^{13}/_{16}$	108	27	$1^{18}/_{27}$	164	41	$1^{4}/_{41}$	235	47	$^{36}/_{47}$	400	20	$^{9}/_{20}$
26	39	$6^{36}/_{39}$	65	39	$2^{20}/_{39}$	110	33	$1^{21}/_{33}$	165	33	$1^{3}/_{33}$	237	79	$^{60}/_{79}$	410	41	$^{18}/_{41}$
27	27	$6^{18}/_{27}$	66	33	$2^{24}/_{33}$	111	37	$1^{23}/_{37}$	166	83	$1^{7}/_{83}$	240	48	$^{36}/_{48}$	420	21	$^{9}/_{21}$
28	49	$6^{21}/_{49}$	67	67	$2^{47}/_{67}$	112	28	$1^{17}/_{28}$	168	28	$1^{2}/_{28}$	243	27	$^{20}/_{27}$	430	43	$^{18}/_{43}$
29	29	$6^{6}/_{29}$	68	17	$2^{11}/_{17}$	114	19	$1^{11}/_{19}$	170	34	$1^{3}/_{34}$	244	61	$^{45}/_{61}$	440	44	$^{18}/_{44}$
30	—	6	69	23	$2^{14}/_{23}$	115	23	$1^{13}/_{23}$	171	38	$1^{2}/_{38}$	245	49	$^{36}/_{49}$	450	27	$^{18}/_{27}$
31	31	$5^{25}/_{32}$	70	49	$2^{28}/_{49}$	116	29	$1^{16}/_{29}$	172	43	$1^{2}/_{43}$	246	41	$^{30}/_{41}$	460	46	$^{18}/_{46}$
32	16	$5^{10}/_{16}$	71	71	$2^{38}/_{71}$	117	39	$1^{21}/_{39}$	174	29	$1^{1}/_{29}$	248	62	$^{45}/_{62}$	465	31	$^{12}/_{31}$
33	33	$5^{15}/_{33}$	72	20	$2^{10}/_{20}$	118	59	$1^{31}/_{59}$	175	35	$1^{1}/_{35}$	249	83	$^{60}/_{83}$	470	47	$^{18}/_{47}$
34	17	$5^{5}/_{17}$	73	73	$2^{34}/_{73}$	120	20	$1^{10}/_{20}$	176	44	$1^{1}/_{44}$	250	25	$^{18}/_{25}$	480	24	$^{9}/_{24}$
35	49	$5^{7}/_{49}$	74	37	$2^{16}/_{37}$	122	61	$1^{29}/_{61}$	177	59	$1^{1}/_{59}$	252	42	$^{30}/_{42}$	490	49	$^{28}/_{49}$
36	—	5	75	20	$2^{8}/_{20}$	123	41	$1^{19}/_{41}$	178	89	$1^{1}/_{89}$	260	33	$^{27}/_{33}$	500	25	$^{9}/_{25}$
37	37	$4^{32}/_{37}$	76	19	$2^{7}/_{19}$	124	31	$1^{14}/_{31}$	180	—	1	261	29	$^{20}/_{29}$	510	34	$^{12}/_{34}$
38	19	$4^{14}/_{19}$	77	77	$2^{26}/_{77}$	125	25	$1^{11}/_{25}$	183	61	$^{60}/_{61}$	264	44	$^{30}/_{44}$	520	26	$^{9}/_{26}$
39	39	$4^{24}/_{39}$	78	39	$2^{12}/_{39}$	126	21	$1^{9}/_{21}$	184	46	$^{45}/_{46}$	265	53	$^{36}/_{53}$	530	53	$^{18}/_{53}$
40	20	$4^{10}/_{20}$	79	79	$2^{22}/_{79}$	128	32	$1^{13}/_{32}$	185	37	$^{36}/_{37}$	267	89	$^{60}/_{89}$	540	27	$^{9}/_{27}$
41	41	$4^{16}/_{41}$	80	20	$2^{5}/_{20}$	129	43	$1^{17}/_{43}$	186	31	$^{30}/_{31}$	270	27	$^{18}/_{27}$	550	55	$^{18}/_{55}$
42	21	$4^{6}/_{21}$	81	27	$2^{6}/_{27}$	130	39	$1^{15}/_{39}$	188	47	$^{45}/_{47}$	275	55	$^{36}/_{55}$	560	28	$^{9}/_{28}$
43	43	$4^{8}/_{43}$	82	41	$2^{8}/_{41}$	132	33	$1^{12}/_{33}$	189	21	$^{20}/_{21}$	276	46	$^{30}/_{46}$	570	38	$^{12}/_{38}$
44	33	$4^{3}/_{33}$	83	83	$2^{14}/_{83}$	134	67	$1^{23}/_{67}$	190	19	$^{18}/_{19}$	280	28	$^{18}/_{28}$	580	29	$^{9}/_{29}$
45	—	4	84	21	$2^{3}/_{21}$	135	27	$1^{9}/_{27}$	192	32	$^{30}/_{32}$	282	47	$^{30}/_{47}$	600	20	$^{6}/_{20}$
46	23	$3^{21}/_{23}$	85	17	$2^{2}/_{17}$	136	34	$1^{11}/_{34}$	195	26	$^{24}/_{26}$	285	38	$^{24}/_{38}$	700	35	$^{9}/_{35}$
47	47	$3^{39}/_{47}$	86	43	$2^{4}/_{43}$	138	23	$1^{7}/_{23}$	196	49	$^{45}/_{49}$	288	48	$^{30}/_{48}$	800	40	$^{9}/_{40}$
48	20	$3^{15}/_{20}$	87	19	$2^{2}/_{19}$	140	49	$1^{14}/_{49}$	198	33	$^{30}/_{33}$	290	29	$^{18}/_{29}$	900	20	$^{4}/_{20}$
															1000	50	$^{9}/_{50}$

e. COMPOUND INDEXING.

A large number of divisions are given in tables IX—XIII. If the numbers of holes given in the tables are not to be found on the index plates but another fraction of the same value can be obtained, the denominater of which is under the number of holes on the index plates, this can be employed in place thereof, but a large number of divisions will have to be passed over as it is absolutely necessary with this manner of indexing that one of the factors or a multiple thereof should appear among the divisions on the index plate. It is however, possible by the compound system of indexing to cut a large number of intermediate divisions, which are either indivisible or if divisible, neither of the factors are included among the number of holes on the index plates.

Instead of working with one circle of holes and one crankhandle two index settings are taken, both circles being on the same index plate, one on the front and one on the back, (see figs. 184 and 185). Let the first circle be termed p, the holes enclosed by the sector $q + 1$, the fraction will consequently be $\frac{q}{p}$.

Let the second circle be termed z, the holes enclosed by the sector $y + 1$, the fraction will thus be $\frac{y}{z}$.

Taking the two circles together, the resulting fraction will then be $\frac{q}{p} + \frac{y}{z}$.

To make this quite clear, let the circles contain respectively 11 and 13 holes.

The ordinary locking pin will be in circle 11, the second locking pin in 13.

If the locking pin is set one hole further the worm will have made $\frac{1}{11}$ revolution.

If now the locking pin the circle z be moved *on* one hole, the worm will have again completed $\frac{1}{13}$ revolution. The total rotary motion n of the worm will thus be equivalent to:—

$$n = \frac{1}{p} + \frac{1}{z} = \frac{1}{11} + \frac{1}{13} = \frac{13}{143} + \frac{11}{143} = \frac{24}{143}.$$

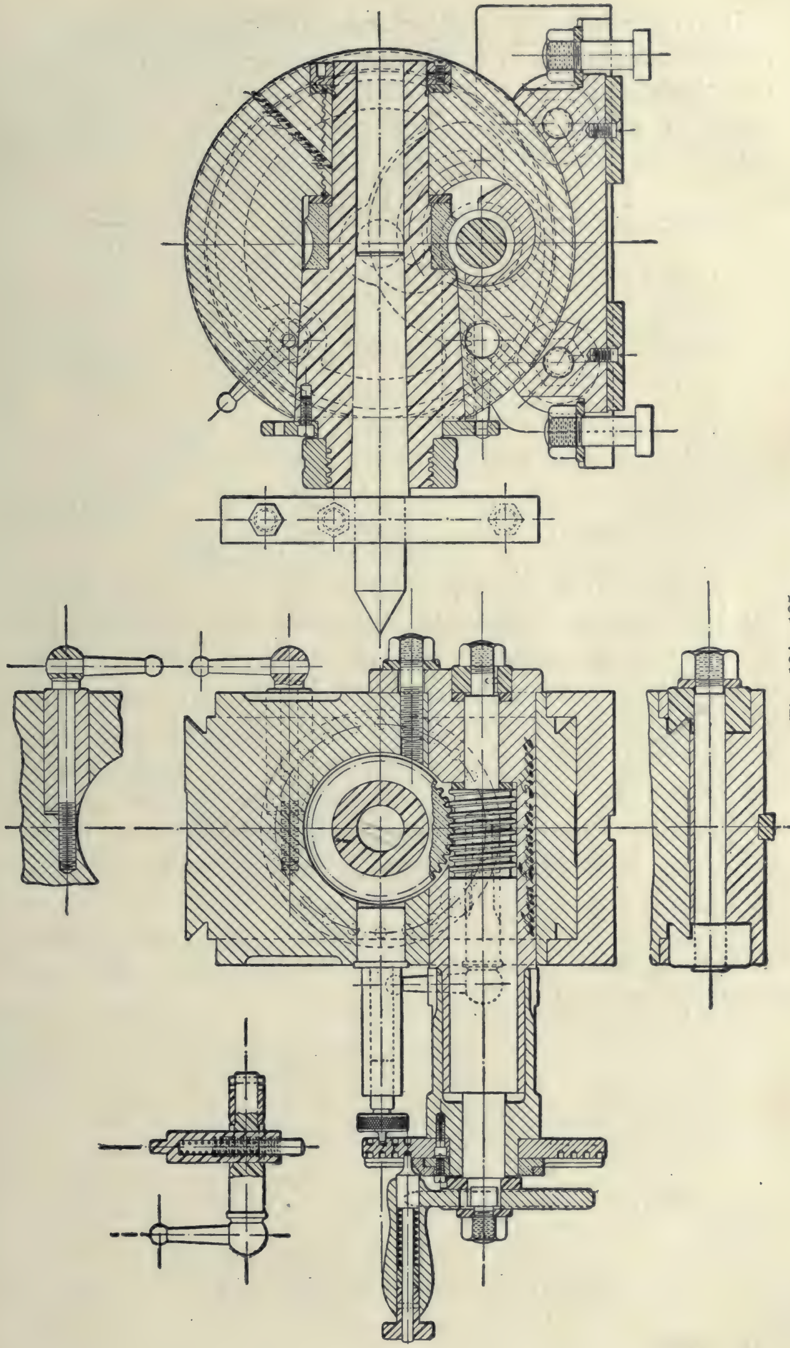


Fig. 184—185.

Longitudinal and transverse section of Le Blond dividing head.

If, on the contrary, the locking pin on circle z be moved *back* one hole, i. e. in a direction contrary to that in which the crankhandle over p moved, the rotary motion of the worm of $\frac{1}{11}$ revolution caused by the first crankhandle will be *diminished* by $\frac{1}{13}$ revolution, the result being:—

$$n = \frac{1}{p} - \frac{1}{z} = \frac{1}{11} - \frac{1}{13} = \frac{13}{143} - \frac{11}{143} = \frac{2}{143}.$$

A second case:— locking pin of circle p is in 5.
„ „ „ „ z „ „ 6.

Locking pin of circle p moved on one division $= \frac{1}{5}$.
„ „ „ „ z „ „ „ „ $= \frac{1}{6}$.
Result $n = \frac{1}{5} + \frac{1}{6} = \frac{6}{30} + \frac{5}{30} = \frac{11}{30}$.

Locking pin of circle p moves on one division $= \frac{1}{5}$.
„ „ „ „ z „ back „ „ $= \frac{1}{6}$.
Result $n = \frac{1}{5} - \frac{1}{6} = \frac{6}{30} - \frac{5}{30} = \frac{1}{30}$.

Acting in this manner, a large number of intermediate fractions can be found in the higher divisions. The number must, however, comply with one condition, viz:—It must be possible to resolve the number into 2 factors. Numbers which are wholly indivisible cannot therefore be taken into consideration, whilst the circle of holes used must contain one of the two factors. If, however, the number can be resolved into two factors, which are generally small, there will be a circle of holes in which each of the two factors appears.

If the division is accomplished with both crankhandles in one direction, the following formulas may then be generally accepted:—

$$(9) \quad n = \frac{q}{p} + \frac{y}{z}.$$

In a contrary direction (10) $n = \dfrac{q}{p} - \dfrac{y}{z}$,

as a consequence, it follows from (7) $\dfrac{o}{v} = n$.

$$\frac{o}{v} = \left(\frac{q}{p} + \frac{y}{z}\right) \text{ or } \left(\frac{q}{p} - \frac{y}{z}\right).$$

(1) Example:— $t = 80.$ $g = 2.$ $v = 51.$

$$o = \frac{t}{g} = \frac{80}{2} = 40.$$

$$n = \frac{o}{v} = \frac{q}{p} + \frac{y}{z} = \frac{40}{51} = \frac{40}{3 \times 17} = \frac{2}{3} + \frac{2}{17} = \frac{34}{51} + \frac{6}{51}.$$

3 and 17 are thus the factors to be found in the number of holes on the index plates, one of which is the circle p, the other the circle z.

17 and 21 can usually be found. 21 is therefore adopted for circle p and 17 for z. From these the fractions $\frac{14}{21} + \frac{2}{17}$ are obtained, which an together equal to $\frac{40}{51}$.

(2) Example:— $t = 40.$ $g = 1.$ $v = 57.$

$$n = \frac{o}{v} = \frac{q}{p} + \frac{y}{z} = \frac{40}{57} = \frac{40}{3 \times 19} = \frac{1}{3} + \frac{7}{19} = \frac{19}{57} + \frac{21}{57}.$$

3 and 19 are the factors to be looked for in the number of holes on the index plate. Taking 21 and 19, the fractions $\frac{7}{21} + \frac{7}{19}$, which together equal $\frac{40}{57}$, are obtained.

The dividing head of Brown & Sharpe and Le Blond shown in fig. 186, is used for obtaining divisions which are unobtainable in the ordinary manner with index plates and is far more effective and easier to calculate than the compound indexing with two circles of different numbers of holes. At one side of the dividing head is a shear with gear wheels. These gear wheels are not used for milling spirals, for in that case one of these wheels would be mounted on the feed screw of the table, but work in connection with the index plate.

The head spindle, on which the wormwheel is mounted, has a projection out of the head on which projection is keyed a gear wheel; a small side shaft, placed somewhat higher up at right angles to the worm, is made to rotate by means of intermediate gears imparting motion to the index plate by means of two bevel and two spur gears, the two set of gears being in the ratio of 1 : 1.

The manner of working is as follows: The crankhandle is keyed to the wormshaft, so that if the taper pin does not lock the index plate, the worm and index plate are disconnected. By turning the crankhandle motion is transmitted to the worm; through the worm the wormwheel; through the wormwheel the spindle; through the spindle the gear wheel on the spindle outside the head; through this gear wheel the change gears with the side shaft; finally, through the side shaft and the two sets of bevel and spur wheels, the index plate.

The result is that in turning the crankhandle over the index plate, the latter is also set in motion either faster or slower according to the ratio of the change gears.

By the use of two intermediate gears instead of one between the gear on the head spindle and the gear on the side shaft, (two gears on one spindle as shown in fig. 186, effect the same purpose, as far as direction of motion is concerned, as one gear), the index plate can also be made to revolve in an opposite direction.

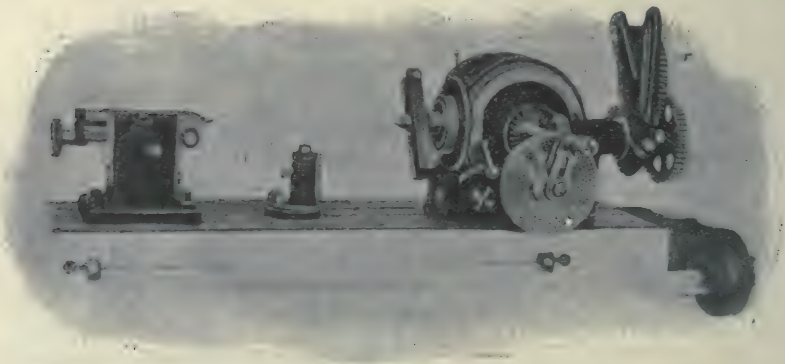


Fig. 186. Le Blond dividing head.

To take a simple example:—The worm wheel has 40 teeth. The worm is single-threaded. Two gears with the same number of teeth are placed one on the head spindle the other on the side shaft with an idle gear between, the number of teeth on this idle gear make no difference whatever), and it is treated *as if* 40 divisions had to be made, i. e. the crankhandle is given a complete turn, the locking pin being thus returned to the same hole in the index plate. What has, however, taken place in the meantime? Seeing that the ratio of the change gears between the spindle and the index plate is 1 : 1, not only has the spindle been turned but the index plate has also made $\frac{1}{40}$ revolution in *the same direction* as that in which the crankhandle was turned; the crankhandle must, consequently, having completed one turn, still be turned $\frac{1}{40}$ revolution farther in order to place the plunger in same hole of the index plate so that after 39 turns of the crankhandle by which the locking pin is placed each time in the same hole, the spindle will have just completed one revolution and the workpiece will thus be divided into 39 divisions. If a second idle gear be inserted, (the no: of teeth being chosen at will), the index plate will revolve in an *opposite* direction to that, the spindle will have only completed one full revolution after 41 turns of the crankhandle and the workpiece will be divided, as a consequence, into 41 divisions. It is evident that by varying the gearing between the head spindle and side shaft, (the two spindles are parallel to one another), any number of divisions can be obtained.

A few examples will serve to make this still clearer.

(1) Example:

The worm wheel has 40 teeth, the worm is single-threaded the required divisions being 93.

$$t = 40. \qquad g = 1. \qquad v = 93.$$

In place of v some approximate number is chosen that can be obtained with the index plate in the ordinary way, say, for instance, 100.

$$o = \frac{t}{g} = \frac{40}{1} = 40.$$

$$n = \frac{o}{v} = \frac{40}{100} = \frac{6}{15}.$$

The locking pin must thus be placed each time 6 holes further forward on a circle with 15 holes but this of course, would give 100 divisions. Only 93 divisions are, however, required, so that, during one full revolution of the spindle, the index plate must be advanced $7 \times \frac{6}{15} = \frac{42}{15}$. To obtain this, a wheel with 42 teeth is mounted on the head spindle and one with 15 teeth on the side shaft, an idle gear being chosen at will. Should there be no wheel with 42 teeth, a compound gearing is used to serve as an auxillary:—

$$\frac{42}{15}=\frac{6\times 7}{3\times 5}=\frac{30\times 35}{15\times 25}.$$

35 is mounted on the head spindle.
25 „ „ „ „ side shaft.

15 and 30 are mounted as a compound gear, so that 15 meshes 35 and 30 meshes 25.

The following examples are self-evident and need no further explanation:—

(2) $t=40.\quad g=1.\quad v=107.\quad o=40.$

v is taken as $=100.$

$$n=\frac{o}{v}=\frac{40}{100}=\frac{6}{15},$$

the no: of divisions must, however, be 107.

The spindle must consequently be retarded $7\times\frac{6}{15}$. The gears must thus be $\frac{42}{15}=\frac{30\times 35}{15\times 25}$ with a fifth idle gear chosen at will.

(3) $t=80.\quad g=2.\quad v=67.\quad o=40.$

v is taken as $=60.$

$$n=\frac{o}{v}=\frac{40}{60}=\frac{10}{15},$$ thus, 7 divisions short.

The spindle must be retarded $\frac{7\times 2}{3}=\frac{40\times 35}{15\times 20}$ with the addition of a fifth idle gear chosen at will.

Or, v may be taken as equivalent to 65.

$n=\frac{o}{v}=\frac{40}{65}=\frac{8}{13}$, in which case the spindle must be retarded $\frac{2\times 8}{13}=\frac{16}{13}$ with two idle gears chosen at will.

(4) $t=120.\quad g=2.\quad v=117.\quad o=60.$

v is taken as $=120.$

$$n=\frac{o}{v}=\frac{60}{120}=\frac{1}{2},$$ *i. e.* 3 divisions too many.

The spindle must therefore be advanced $\frac{3}{2} = \frac{30}{20}$ with any idle gear at will.

(5) $$t = 80. \quad g = 1. \quad v = 77. \quad o = 80.$$

$$v \text{ is taken as} = 80.$$

$$n = \frac{o}{v} = 1, \text{ \textit{i. e.} 3 divisions too many.}$$

The spindle must be advanced $\frac{3}{1} = \frac{90}{30}$ with any idle gear at will.

(6) $$t = 60. \quad g = 1. \quad v = 241. \quad o = 60.$$

$$v \text{ is taken as} = 240.$$

$$n = \frac{o}{v} = \frac{60}{240} = \frac{1}{4} = \frac{5}{20}, \text{ \textit{i. e.} one division short.}$$

The spindle must be retarted $1 \times \frac{5}{20} = \frac{25 \times 20}{50 \times 40}$ with any idle gear at will.

(7) $$t = 120. \quad g = 2. \quad v = 37. \quad o = 60.$$

$$v \text{ is taken as} = 40.$$

$$n = \frac{o}{v} = \frac{60}{40} = 1\frac{1}{2} = 1\frac{10}{20}, \text{ \textit{i. e.} 3 divisions too many.}$$

The spindle must be advanced $3 \times \frac{6}{4} = \frac{18}{4} = \frac{90 \times 40}{40 \times 20}$.

(8) $$t = 80. \quad g = 1. \quad v = 53. \quad o = 80.$$

$$v \text{ is taken as} = 50.$$

$$n = \frac{o}{v} = \frac{80}{50} = 1\frac{3}{5} = 1\frac{9}{15}, \text{ i. e. 3 divisions short.}$$

The spindle must be *retarded* $3 \times \frac{8}{5} = \frac{24}{5} = \frac{30 \times 80}{25 \times 20}$.

The gears used for this purpose are usually the same as those used for spiral milling, as division of indivisable numbers with gear wheels and spiral milling cannot take place at the same time.

An exact number of divisions is, moreover, only necessary in the case of gear wheels and other work of the kind. Whenever spiral grooves have to be milled, as in the case of cutters, etc., a definite number of divisions is, as a rule, not imperative, and the divisions can generally be determined according to the number which can be obtained with the ordinary indexing without recourse to differential indexing.

f. PRACTICAL DIRECTIONS FOR MILLING CUTTER TEETH.

Finally, we will proceed to give a short description of practical milling. The cutter is mounted on an arbor placed between the centres and rotates with the spindle of the dividing head by means of carrier. This, however, may not take place as is the case with lathe work; the connection between the workpiece and the spindle of the dividing head must be absolute, or in any case, of such a nature, that it is impossible for the workpiece to make the slightest movement independent of the head spindle. To effect this, the head spindle nose is provided with a double-forked carrier. The arbor on which the cutter blank is mounted is provided with a dog, the bolt in the fork on the head-spindle screws up the dogtail placed on the workpiece so that there is no play between the dog and the carrier.

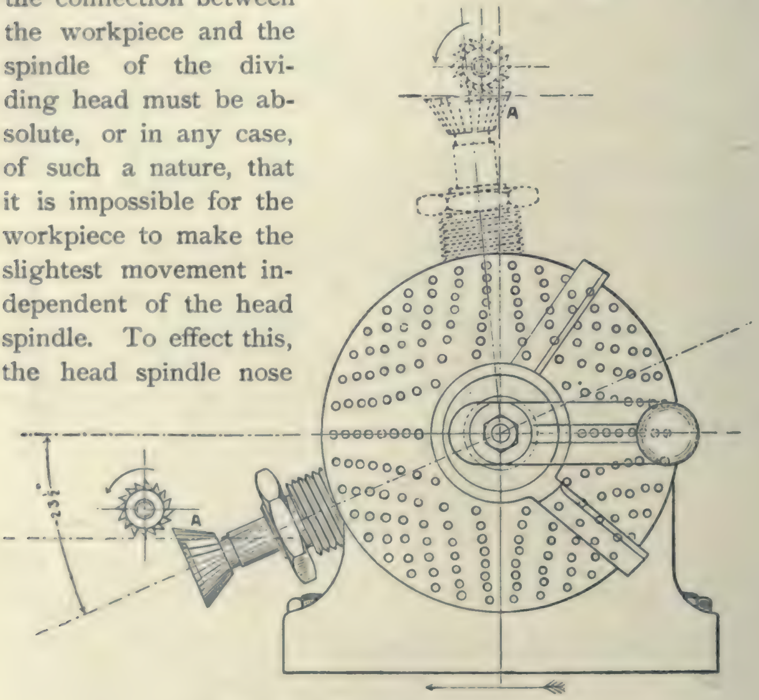


Fig. 187. Milling angular cutters.

When milling angular cutters, they are mounted on a spindle which fits with a taper shank directly in the conical bore of the head spindle, (figs. 187 and 188).

The milling table is adjusted to the exact position in a transverse direction in such a manner that the extension of teeth, which cuts the cutting plane of the teeth, to be milled passes exactly over the centre of the cutter blank. After this, the working cutter is set at the required depth.

The required index plate is then mounted on the dividing head, the locking pin being set on the crankhandle so that its point corresponds exactly with the holes of the desired circle. The sector is then set to the required angle; for instance, if the crankhandle has to pass over 9 holes in circle 21, the sector must cover 10 holes, (see fig. 183, page 111).

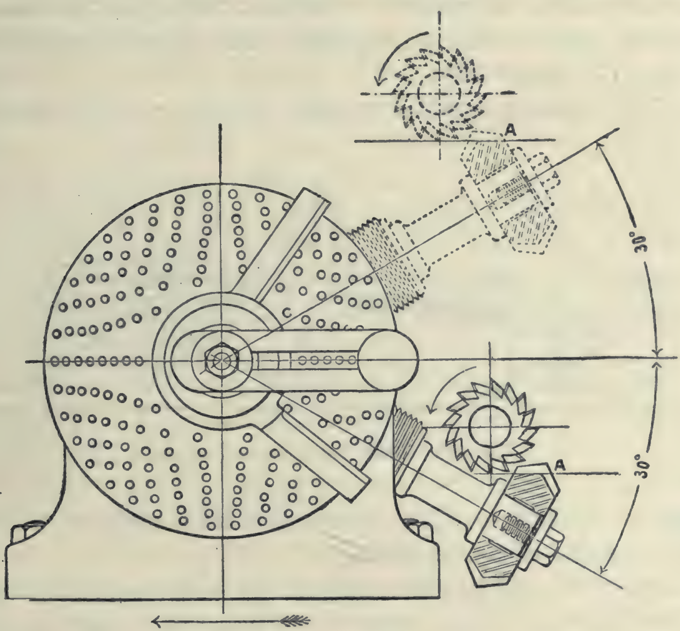


Fig. 188. Milling double angular cutters.

The work can now be commenced. One leg of the sector is placed against the locking pin; when one groove has been cut and the table has been returned, the crankhandle is turned till the locking pin is just against the hole lying immediately inside the other leg of the sector, into which it is pushed by the plunger spring, the sector being shifted in the same direction as the crankhandle, with its leg once more against the locking pin. The further progress of the work is identically the same.

Care must be taken that the crankhandle is not turned over too far so that it will be necessary to turn back, since the least play between the worm and worm wheel will result in an incorrect division. Therefore directly any play is noticed, it must be remedied. It is for this reason that the worm wheel is wedged as has already been shown in fig. 173, page 103.

When milling angular cutters, the cutter it mounted in such a manner that the cutting can be completed without the necessity of dismounting.

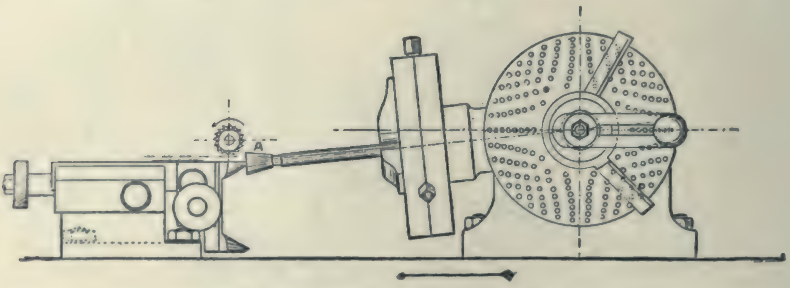


Fig. 189. Milling small angular cutters.

Figs. 187 and 188 show the position of two angular cutters of different form and need no explanation, whilst fig. 189 shows the manner of milling a small angle cutter which forms one whole with the shank. It is mounted in a universal chuck on the dividing head, the other end carried by the back centre of the tailstock is arranged in such a manner that it can be set lower than the centre line of the dividing head. Of late, the back centre on the tailstock has been altered in such a manner as to permit of its being placed at an angle which effectually prevents the possibility of any oscillation on one side of the centre.

g. SPIRAL MILLING.

Thus far we have exclusively treated of the division of the circumference of a cutter or other object into a certain number of divisions. As the reader will have observed, we have gone much farther than was necessary for the milling of an ordinary cutter, as the necessity of dividing a certain number of divisions to the exclusion of all other approximate numbers will never really occur in the ordinary milling of cutters. We have treated and in the following pages shall continue to treat of the calculations which occur and which are connected with the handling of the dividing head on the universal milling machine but shall continue to take the cutter as starting point.

So far we have exclusively dealt with the milling of a cutter with straight teeth; during the process of milling the longitudinal motion of the table was rectangular to the main spindle of the milling machine whilst only the working cutter rotated.

When, however, in addition to the longitudinal movement of the table, a slow rotary motion is imparted to the workpiece at the same time, the result is a spiral line.

In milling spirals the longitudinal movement of the table can no longer be rectangular to the main spindle, but both form a certain angle. The spiral or inclination and the angle at which the table must be placed are dependent one on the other; no spiral can be cut without fixing the angle, no angle can be determined without the spiral to be cut being known. Both are, however, calculated quite separately and can, consequently, be treated independently.

The first difference between the milling of straight and spiral teeth is that whilst in the case of straight teeth, care must be taken that the index plate is locked up after the crankhandle has completed the necessary turn, in the latter case the locking pin must be free of the index plate as during the process of milling the crankhandle will rotate over the index plate. The manner in which the head spindle is caused to rotate during the longitudinal movement of the table has already been illustrated in fig. 174, whilst fig. 190 gives a still clearer illustration of the connection between the feed screw and the spindle of the dividing head by means of change gears.

On the feed screw U in fig. 174, page 104, which imparts longitudinal motion to the table, is mounted the gear wheel *a* which meshes an idle wheel chosen at will or as in fig. 174, a set of compound wheels one of which meshes the wheel *b* which is placed on the spindle of the dividing head and in this manner a permanent connection is brought about between the feed screw of the table and the spindle of the dividing head.

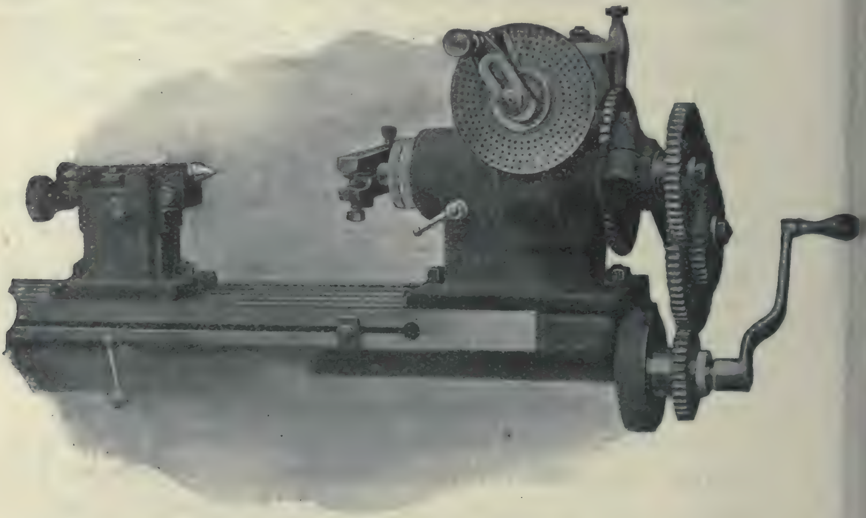


Fig. 190. Dividing head set up for spiralmilling.

A simple example will show clearly what actually takes place.

Given that the wormwheel has 60 teeth, that the worm is single-threaded whilst the feed screw has a $^1/_4$ inch pitch.

Set one wheel, on the feed screw U fig. 174, another on the side shaft P, both of same number of teeth with an idle wheel on the stud O. When the feed screw U has completed one revolution, the worm shaft will have also revolved once and the worm wheel will have shifted one tooth; the spindle of the dividing head together with the workpiece will consequently have completed $\frac{1}{60}$ of a revolution; for one complete revolution the feed screw must make 60 revolutions whilst the table, and with it the workpiece will have traversed $60 \times \frac{1}{4}$ inch $= 15$ inches. The length of the spiral, in this case will, therefore, amount to 15 inches.

When the feed screw has made 60 revolutions, the head spindle and workpiece will have just completed one turn.

For the sake of explanation we first considered the gear wheels; in actual practice it will be just the reverse, the gears and the inclination depending upon the given length of the spiral or the spiral and the gears on the given inclination.

Let us take the simplest case, viz:—the calculation of the change gears for a spiral of a given length, in other words, the longitudinal motion of the workpiece for one complete revolution.

This calculation is very similar to the calculation of the change gears for thread-cutting on the lathe. In the latter case, the starting point is the number of threads per unit of length of the lead screw, whilst here we start with the number of teeth on the worm wheel divided by the number of threads per inch of the feed screw which is equivalent to the length of the spiral. Thus, in the foregoing example $\frac{60}{4} = 15$ inches.

This, however, only applies when $g = 1$, i. e. is a single-threaded worm. If the worm has more threads, the number of teeth of the worm wheel must be divided by the product of the number of threads of the worm and the number of threads per inch of the feed screw.

The number of *threads* of the worm must not be confused with the number of *threads per inch* of the feed screw. If in the foregoing example $g = 2$, the length of the spiral would have been $\frac{60}{2 \times 4} = 7\frac{1}{2}$ inches.

Example: $t = 40$. $g = 1$.

Taking the number of threads of the feed screw per inch as $s = 4$ and the length of the spiral to be cut as $l = 20$ inches, the constant in this case will then be $\frac{40}{4} = 10$, whilst the ratio between the change gears a and b in fig. 174 must be $20 : 10$.

Assuming that:—

a is the gear on the dividing head, or, in the case of compound gearing, the gears which are driven.

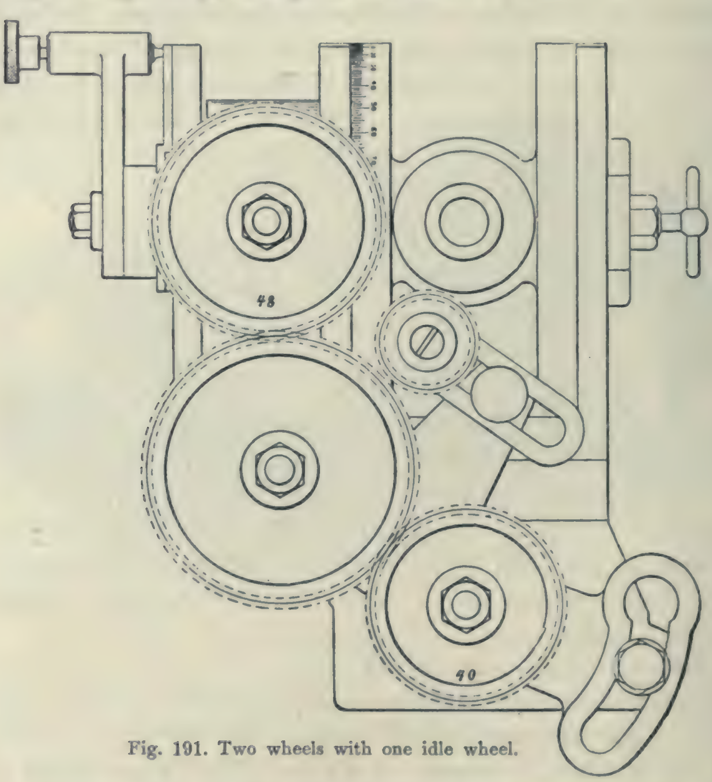


Fig. 191. Two wheels with one idle wheel.

b is the gear on the feed screw or the driving gear.

c is the constant obtained from $\frac{t}{g\,s}$.

X is the length of the spiral to be cut, we arrive at the general formula:—

$$a : b = X : c. \tag{11}$$

If no fraction can be formed from $\frac{a}{b}$ in which of the numerator as well as of the denominator, are change gears with that number of teeth, the work can be accomplished with 4 wheels.

Fig. 191 shows the manner of placing two wheels with an idle gear at will, whilst fig. 192 shows the same for mounting compound gearing.

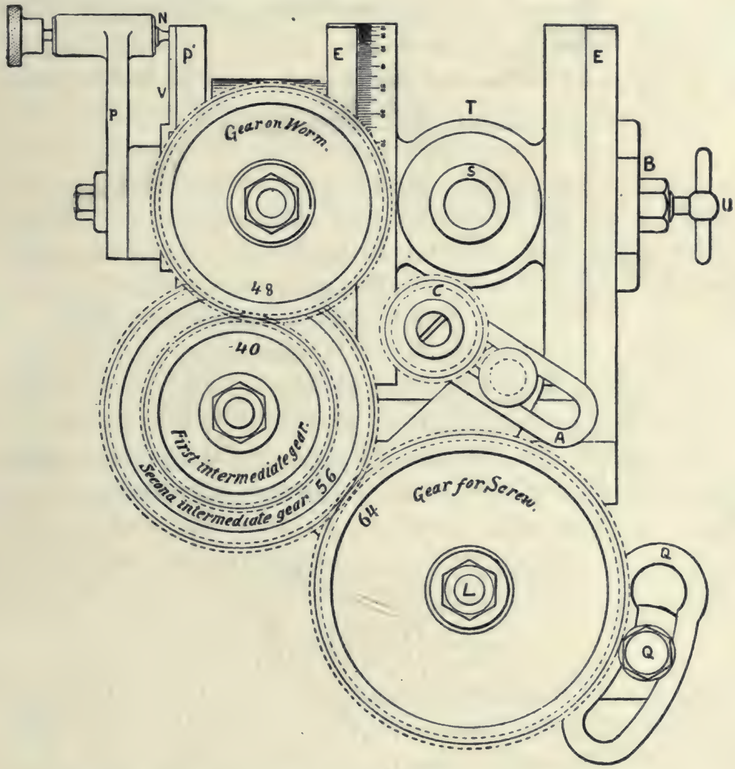


Fig. 192. Compound gearing between feed screw and head spindle.

The driven and driving gears may be interchanged, though they may not be changed in pairs or separately. The gear resulting from the constant *c* must invariably be placed on the feed screw and serve as driving gear whilst the gear resulting from X must be placed on the dividing head or act as a gear which is driven.

We will now give a few examples which will serve to explain the calculation.

(1) $t = 80.\quad g = 2.\quad s = 4.\quad l = 24$ inches.

$$c = \frac{t}{g \cdot s} = \frac{80}{2 \times 4} = 10.\quad X = 24.$$

$$\frac{a}{b} = \frac{24}{10} = \frac{48}{20}$$

The gear with 48 teeth is mounted on the dividing head, that with 20 teeth on the feed screw with an idle wheel engaging both.

(2) $t = 120.\quad g = 2.\quad s = 4.\quad l = 60$ inches.

$$c = \frac{t}{g \cdot s} = \frac{120}{2 \times 4} = 15.\quad X = 60.$$

$$\frac{a}{b} = \frac{60}{15} = \frac{10 \times 6}{3 \times 5} = \frac{50 \times 30}{15 \times 25}.$$

The gears with 15 and 25 teeth are the driving gears, those with 30 and 50 teeth the gears to be driven.

(3) $t = 40.\quad g = 1.\quad s = 4.\quad l = 125$ inches.

$$c = 10.\quad X = 125.$$

$$\frac{a}{b} = \frac{125}{10} = \frac{5 \times 25}{1 \times 10} = \frac{25 \times 50}{10 \times 10} = \frac{75 \times 100}{30 \times 20}$$

The gears with 20 and 30 teeth are the driving gears, those with 75 and 100 teeth the gears to be driven.

(4) $t = 180.\quad g = 3.\quad s = 4.\quad l = 5\frac{1}{2}$ inches.

$$c = \frac{180}{3 \times 4} = 15.\quad X = 5\tfrac{1}{2}.$$

$$\frac{a}{b} = \frac{5\frac{1}{2}}{15} = \frac{11}{30} = \frac{22}{60}.$$

The gear with 22 teeth is mounted on the dividing head, that with 60 teeth being placed on the feed screw with an idle gear.

(5) $t = 60.\quad g = 1.\quad s = 5.\quad l = 9\frac{3}{4}$ inches.

$$c = \frac{t}{g \cdot s} = 12.\quad X = 9\tfrac{3}{4}.$$

$$\frac{a}{b} = \frac{9\frac{3}{4}}{12} = \frac{39}{48} \text{ or } \frac{26}{32}.$$

(6) $t = 80.\quad g = 2.\quad s = 5.\quad l = 28\frac{7}{8}$ inches.

$$c = \frac{t}{g \cdot s} = \frac{80}{2 \times 5} = 8.\quad X = 28\tfrac{7}{8}.$$

$$\frac{a}{b} = \frac{28\frac{7}{8}}{8} = \frac{231}{64} = \frac{3 \times 7 \times 11}{4 \times 16} = \frac{33 \times 70}{20 \times 32}.$$

The foregoing examples are sufficiently clear in themselves so that further explanation is unnecessary.

h. THE CALCULATION OF THE LEAD FROM THE INCLINATION.

In what has previously been said, it has been taken for granted that the *length* of the spiral, or what is just the same, the lead, has either been known or been given. In actual millling, however, it is usually just this length which is not given, since it is customary to start from the angle formed by the tooth of the cutter and its axis. Moreover, what has previously been said is still incomplete as, before the milling can be commenced, it is necessary to know precisely at what angle the table must be placed in order to secure a certain spiral line.

By constructing a triangle on the drawing table the exact angle can always be determined when the lead of the spiral is known, or vice versa, the lead of the spiral can be determined when the angle is known, since two elements of the right angled triangle which is to be constructed are always known, viz:—one side of the right angle and one angle, or the two sides of the right angle; the side of the right angle which is always constant being the contour of the cutter.

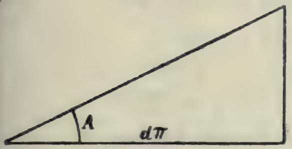


Fig. 193.

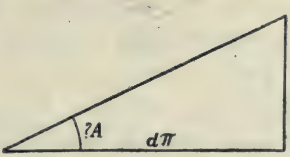


Fig. 194.

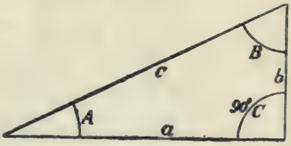


Fig. 195.

Fig. 193 represents the first case in which given ∠ A, the lead of the spiral is to be determined.

Fig. 194 illustrates the second case in which given the lead of the spiral, ∠ A is to be determined.

This manner of working is, however, troublesome, not accurate, and, we only mention it here in order to be complete.

The angle can be determined quickly and with mathematical accuracy by means of goniometry with which, however, the workman is usually not so familiar.

For this reason we shall now proceed to explain just as much of this subject as is necessary for our purpose, viz:—to determine an angle when the two sides are known or to determine a side, given one side and one angle. The right angle is naturally always known and is 90°.

Fig. 195 represents a right angled triangle, the sides being marked a, b and c, and the angles A, B, and C.

$b : c$ is termed the *sine* of angle A.
$a : c$ „ „ „ *cosine* „ „ A.
$b : a$ „ „ „ *tangent* „ „ A.
$a : b$ „ „ „ *cotangent* „ „ A.
$c : a$ „ „ „ *sector* „ „ A.
$c : b$ „ „ „ *cosector* „ „ A.

The principal object of plane trigonometry is to find out from any three elements of a triangle, (not being all angles), how to determine the remaining three.

Supposing the side a in fig. 195 = 5 and the side $b = 4$,

then Tangent $A = \frac{4}{5} = 0.8$
Cotangent $A = \frac{5}{4} = 1.25$.

Tangent and *cotangent* are defined as follows:—

When a certain part in one arm of an acute angle is projected on the other arm and in a line standing at right angles to the other arm, the proportion of the second projection to the first is termed the *tangent* of that angle.

When a certain part in one arm of an acute angle is projected on the other arm and in a line standing at right angles to the other arm, the proportion of the first projection to the second is termed the *cotangent* of that angle.

Now, in the case of $\angle$B, fig. 195, b is the first projection and a the second.

$b : a$ is consequently *cotangent* B.

$a : b$ in the same illustration being *tangent* B.

Hence it follows that the cotangent of an acute angle is equal to the tangent of its complement.

The tangent of an acute angle is equal to the cotangent of its complement.

(The complement of an angle is the angle which must supplement the first in order to obtain an angle of 90^0).

Sine and *Cosine* are thus defined :—

The sine of an acute angle is the proportion of the projection of a certain part in one arm drawn on a line which bisects the second arm at right angles to that arm.

The cosine of an acute angle is the proportion of the projection of a certain part drawn on the one arm to that part.

In the case of $\angle$ B in fig. 195, b is the projection of the part in the one arm, c being the part of the arm; $b : c$ is consequently the cosine of $\angle$ B.

Further, in the case of $\angle$ B, a is the projection of a part in one arm drawn on a line bisecting the other arm at right angles, c being the arm; consequently $a : c$ is the sine of $\angle$ B.

From this it follows that the cosine of an acute angle is equal to the sine of its complement.

The sine of an acute angle is equal to the cosine of its complement.

Seeing that sectors and cosectors are the proportions of sides not required in the calculations which follow, they need not be considered here.

The names of the goniometrical proportions are abbreviated as follows:—

Sine = Sin., Cosine = Cos.,
Tangent = Tan., Cotangent = Cotan.

If $\angle$ A fig. 195 is 45^0, then $\angle$ B is also 45^0, and the triangle is equilateral, i. e. a and b are equal, so that

$$\text{Tan. A} = b : a = 1. \text{ Cotan. A} = a : b = 1.$$

With an angle of 45^0 the tan. is thus = 1, the cotan. being equal to the tan.

If $\angle$ A fig. 195 is smaller, the proportion $b : c$, i. e. tan. A is also smaller, until finally when $\angle \text{A} = 0^0$, tan. A becomes equal to zero.

If $\angle$ A is greater, the proportion $b : c$, i. e. tan. A is also greater, until finally when $\angle \text{A} = 90^0$, the line b was parallel to the hypotenuse and is thus immesurable; this is expressed by the sign ∞.

It is precisely the same with the cotan. Tan. and cotan. can thus represent each and every value lying between 0 and ∞. If tan. $= 0$, cotan. will be $= \infty$; if tan. $= \infty$, then cotan. will be $= 0$.

As the sloping side of a right angled triangle is always greater than one of the sides of the right angle and as one of the sides of the right angle must always be divided by the sloping side for sin. or cos., it follows that sin. and cos. of an acute angle are always less than 1.

$$\text{With } 0^0 \text{ sin.} = 0, \text{ cos.} = 1.$$
$$\text{With } 90^0 \text{ sin.} = 1, \text{ cos.} = 0.$$

The goniometrical proportions are dependent on the size of the *angles* but *entirely independent* of the size of the *triangle*.

For example, if in place of the value given on page 138 for fig. 195, we take

$$\text{side } a = 15, \text{ and side } b = 12, \text{ then}$$
$$\text{tan. A} = \tfrac{12}{15} = 0\,.\,8, \text{ cotan. A} = \tfrac{15}{12} = 1\,.\,25$$

which is the same as when the sides a and b have the values 5 and 4.

The goniometrical proportions of all angles from 0^0 to 90^0 have been worked out and arranged in tables.

By this means, if one angle and one side of a right angled triangle an known, the other sides can easily be calculated. For instance, if in the foregoing example tan. $\text{A} = 0\,.\,8$ and it is known that $a = 15$, it follows therefrom that b is $= 15 \times 0\,.\,8 = 12$.

In tables XIV and XV the goniometrical proportions of sin., cos., tan. and cotan. are given to the sixth part of a degree which is sufficient for calculating the angles in connection with the matter in hand. With the assistance of these tables and the foregoing explanations, the angle at which the table must be set for milling spirals can be readily calculated from the data which is always at hand in such cases or the lead of the spiral can be reckoned from the given angle, since two particulars are always known, viz:—

1st. The diameter, i. e. side *a* fig. 193 and the lead of the spiral, i. e. side *b*; ∠B being unknown.

2nd. The diameter, i. e. side *a* fig. 193 and the angle, i. e. ∠B; the lead of the spiral, i. e. side *b* being unknown.

The triangle, fig. 195 is the starting point in the calculation, all proportions such as diameter of the cutter, lead of the spiral, angle, etc. being united therein, as follows:—

1. The diameter of the cutter $= d =$ side *a*.
2. The lead or pitch of the spiral $=$ side *b*.
3. The angle which the spiral forms with the side of the cutter $= \angle A$.
4. The angle which the spiral forms with the axis of the cutter $= \angle B$.

In the following calculations little notice need be taken of ∠A.

∠B is the angle which the tooth forms with the axis of the cutter is consequently the angle at which the table must be placed.

The foregoing is summarized in the following table.

Given.	Required.	Solution.
A and *a*	*b*	$b = a\ tg\ A.$
B and *a*	*b*	$b = a \cot B.$
a and *b*	B	$a/b = tg\ B.$
a and *b*	B	$b/a = \cot B.$
a and *b*	A	$b/a = tg\ A.$
A and *b*	*a*	$a = b \cot A.$
A and *a*	*c*	$c = \frac{a}{\cos A}.$

Table XIV.

Degrees.	SINE.							Degrees.	Degrees.	SINE.							Degrees.
	0′	10′	20′	30′	40′	50′	60′			0′	10′	20′	30′	40′	50′	60′	
0	0.000	0.003	0.006	0.009	0.012	0.015	0.017	89	46	0.719	0.721	0.723	0.725	0.727	0.729	0.731	43
1	0.017	0.020	0.023	0.026	0.029	0.032	0.035	88	47	0.731	0.733	0.735	0.737	0.739	0.741	0.743	42
2	0.035	0.038	0.041	0.044	0.047	0.049	0.052	87	48	0.743	0.745	0.747	0.749	0.751	0.753	0.755	41
3	0.052	0.055	0.058	0.061	0.064	0.067	0.070	86	49	0.755	0.757	0.759	0.760	0.762	0.764	0.766	40
4	0.070	0.073	0.076	0.078	0.081	0.084	0.087	85	50	0.766	0.768	0.770	0.772	0.773	0.775	0.777	39
5	0.087	0.090	0.093	0.096	0.099	0.102	0.105	84	51	0.777	0.779	0.781	0.783	0.784	0.786	0.788	38
6	0.105	0.107	0.110	0.113	0.116	0.119	0.122	83	52	0.788	0.790	0.792	0.793	0.795	0.797	0.799	37
7	0.122	0.125	0.128	0.131	0.133	0.136	0.139	82	53	0.799	0.800	0.802	0.804	0.806	0.807	0.809	36
8	0.139	0.142	0.145	0.148	0.151	0.154	0.156	81	54	0.809	0.811	0.812	0.814	0.816	0.817	0.819	35
9	0.156	0.159	0.162	0.165	0.168	0.171	0.174	80	55	0.819	0.821	0.822	0.824	0.826	0.827	0.829	34
10	0.174	0.177	0.179	0.182	0.185	0.188	0.191	79	56	0.829	0.831	0.832	0.834	0.835	0.837	0.839	33
11	0.191	0.194	0.197	0.199	0.202	0.205	0.208	78	57	0.839	0.840	0.842	0.843	0.845	0.847	0.848	32
12	0.208	0.211	0.214	0.216	0.219	0.222	0.225	77	58	0.848	0.850	0.851	0.853	0.854	0.856	0.857	31
13	0.225	0.228	0.231	0.233	0.236	0.239	0.242	76	59	0.857	0.859	0.860	0.862	0.863	0.865	0.866	30
14	0.242	0.245	0.248	0.250	0.253	0.256	0.259	75	60	0.866	0.867	0.869	0.870	0.872	0.873	0.875	29
15	0.259	0.262	0.264	0.267	0.270	0.273	0.276	74	61	0.875	0.876	0.877	0.879	0.880	0.882	0.883	28
16	0.276	0.278	0.281	0.284	0.287	0.290	0.292	73	62	0.883	0.884	0.886	0.887	0.888	0.890	0.891	27
17	0.292	0.295	0.298	0.301	0.303	0.306	0.309	72	63	0.891	0.892	0.894	0.895	0.896	0.898	0.899	26
18	0.309	0.312	0.315	0.317	0.320	0.323	0.326	71	64	0.899	0.900	0.901	0.903	0.904	0.905	0.906	25
19	0.326	0.328	0.331	0.334	0.337	0.339	0.342	70	65	0.906	0.908	0.909	0.910	0.911	0.912	0.914	24

23	0.391	0.393	0.396	0.399	0.401	0.404	0.407	66	69	0.934							
24	0.407	0.409	0.412	0.415	0.417	0.420	0.423	65	70	0.940	0.941	0.942	0.943	0.944	0.945	0.946	19
25	0.423	0.425	0.428	0.431	0.433	0.436	0.438	64	71	0.946	0.947	0.948	0.949	0.950	0.951	0.952	18
26	0.438	0.441	0.444	0.446	0.449	0.451	0.454	63	72	0.952	0.952	0.953	0.954	0.955	0.955	0.956	17
27	0.454	0.457	0.459	0.462	0.464	0.467	0.469	62	73	0.956	0.957	0.958	0.959	0.960	0.960	0.961	16
28	0.469	0.472	0.475	0.477	0.480	0.482	0.485	61	74	0.961	0.962	0.963	0.964	0.964	0.965	0.966	15
29	0.485	0.487	0.490	0.492	0.495	0.497	0.500	60	75	0.966	0.967	0.967	0.968	0.969	0.970	0.970	14
30	0.500	0.503	0.505	0.508	0.510	0.513	0.515	59	76	0.970	0.971	0.972	0.972	0.973	0.974	0.974	13
31	0.515	0.518	0.520	0.522	0.525	0.527	0.530	58	77	0.974	0.975	0.976	0.976	0.977	0.978	0.978	12
32	0.530	0.532	0.535	0.537	0.540	0.542	0.545	57	78	0.978	0.979	0.979	0.980	0.981	0.981	0.982	11
33	0.545	0.547	0.550	0.552	0.554	0.557	0.559	56	79	0.982	0.982	0.983	0.983	0.984	0.984	0.985	10
34	0.559	0.562	0.564	0.566	0.569	0.571	0.574	55	80	0.985	0.985	0.986	0.986	0.987	0.937	0.988	9
35	0.574	0.576	0.578	0.581	0.583	0.585	0.588	54	81	0.988	0.988	0.989	0.989	0.989	0.990	0.990	8
36	0.588	0.590	0.592	0.595	0.597	0.599	0.602	53	82	0.990	0.991	0.991	0.991	0.992	0.992	0.993	7
37	0.602	0.604	0.606	0.609	0.611	0.613	0.616	52	83	0.993	0.993	0.993	0.994	0.994	0.994	0.995	6
38	0.616	0.618	0.620	0.623	0.625	0.627	0.629	51	84	0.995	0.995	0.995	0.995	0.996	0.996	0.996	5
39	0.629	0.632	0.634	0.636	0.638	0.641	0.643	50	85	0.996	0.996	0.997	0.997	0.997	0.997	0.998	4
40	0.643	0.645	0.647	0.649	0.652	0.654	0.656	49	86	0.998	0.998	0.998	0.998	0.998	0.998	0.999	3
41	0.656	0.658	0.660	0.663	0.665	0.667	0.669	48	87	0.999	0.999	0.999	0.999	0.999	0.999	0.999	2
42	0.669	0.671	0.673	0.676	0.678	0.680	0.682	47	88	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1
43	0.682	0.684	0.686	0.688	0.690	0.693	0.695	46	89	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0
44	0.695	0.697	0.699	0.701	0.703	0.705	0.707	45									
45	0.707	0.709	0.711	0.713	0.715	0.717	0.719	44									
Degrees.	60′	50′	40′	30′	20′	10′	0′	Degrees.	Degrees.	60′	50′	40′	30′	20′	10′	0′	Degrees.
	COSINE.									COSINE.							

Table XV.

Degrees.	TANGENT.							Degrees.	Degrees.	TANGENT.							Degrees.
	0′	10′	20′	30′	40′	50′	60′			0′	10′	20′	30′	40′	50′	60′	
0	0.000	0.003	0.006	0.009	0.012	0.015	0.017	89	45	1.000	1.006	1.013	1.018	1.024	1.030	1.036	44
1	0.017	0.020	0.023	0.026	0.029	0.032	0.035	88	46	1.036	1.042	1.048	1.054	1.060	1.066	1.072	43
2	0.035	0.038	0.041	0.044	0.047	0.049	0.052	87	47	1.072	1.079	1.085	1.091	1.098	1.104	1.111	42
3	0.052	0.055	0.058	0.061	0.064	0.067	0.070	86	48	1.111	1.117	1.124	1.130	1.137	1.144	1.150	41
4	0.070	0.073	0.076	0.079	0.082	0.085	0.087	85	49	1.150	1.157	1.164	1.171	1.178	1.185	1.192	40
5	0.087	0.090	0.093	0.096	0.099	0.102	0.105	84	50	1.192	1.199	1.206	1.213	1.220	1.228	1.235	39
6	0.105	0.108	0.111	0.114	0.117	0.120	0.123	83	51	1.235	1.242	1.250	1.257	1.265	1.272	1.280	38
7	0.123	0.126	0.129	0.132	0.135	0.138	0.141	82	52	1.280	1.288	1.292	1.303	1.311	1.319	1.327	37
8	0.141	0.144	0.146	0.149	0.152	0.155	0.158	81	53	1.327	1.335	1.343	1.351	1.360	1.368	1.376	36
9	0.158	0.161	0.164	0.167	0.170	0.173	0.176	80	54	1.376	1.385	1.393	1.402	1.411	1.419	1.428	35
10	0.176	0.179	0.182	0.185	0.188	0.191	0.194	79	55	1.428	1.437	1.446	1.455	1.464	1.473	1.483	34
11	0.194	0.197	0.200	0.203	0.206	0.210	0.213	78	56	1.483	1.492	1.501	1.511	1.520	1.530	1.540	33
12	0.213	0.216	0.219	0.222	0.225	0.228	0.231	77	57	1.540	1.550	1.560	1.570	1.580	1.590	1.600	32
13	0.231	0.234	0.237	0.240	0.243	0.246	0.249	76	58	1.600	1.611	1.621	1.632	1.643	1.653	1.664	31
14	0.249	0.252	0.256	0.259	0.262	0.265	0.268	75	59	1.664	1.675	1.686	1.698	1.709	1.720	1.732	30
15	0.268	0.271	0.274	0.277	0.280	0.284	0.287	74	60	1.732	1.744	1.756	1.767	1.780	1.792	1.804	29
16	0.287	0.290	0.293	0.296	0.299	0.303	0.306	73	61	1.804	1.816	1.829	1.842	1.855	1.868	1.881	28
17	0.306	0.309	0.312	0.315	0.318	0.322	0.325	72	62	1.881	1.894	1.907	1.921	1.935	1.949	1.963	27
18	0.325	0.328	0.331	0.335	0.338	0.341	0.344	71	63	1.963	1.977	1.991	2.006	2.020	2.035	2.050	26
19	0.344	0.348	0.351	0.354	0.357	0.361	0.364	70	64	2.050	2.066	2.081	2.097	2.112	2.118	2.145	25

24	0.445	0.449	0.452	0.456	0.459	0.463	0.466	65	69	2.605	2.628	2.651	2.675	2.699	2.723	2.747	20
25	0.466	0.470	0.473	0.477	0.481	0.484	0.488	64	70	2.747	2.773	2.798	2.824	2.850	2.877	2.904	19
26	0.488	0.491	0.495	0.499	0.502	0.506	0.510	63	71	2.904	2.932	2.960	2.989	3.018	3.047	3.078	18
27	0.510	0.513	0.517	0.521	0.524	0.528	0.532	62	72	3.078	3.108	3.140	3.172	3.204	3.237	3.271	17
28	0.532	0.535	0.539	0.543	0.547	0.551	0.554	61	73	3.271	3.305	3.340	3.376	3.412	3.450	3.487	16
29	0.554	0.558	0.562	0.566	0.570	0.573	0.577	60	74	3.487	3.526	3.566	3.606	3.647	3.689	3.732	15
30	0.577	0.581	0.585	0.589	0.593	0.597	0.601	59	75	3.732	3.776	3.821	3.867	3.914	3.962	4.011	14
31	0.601	0.605	0.609	0.613	0.617	0.621	0.625	58	76	4.011	4.061	4.113	4.165	4.217	4.275	4.331	13
32	0.625	0.629	0.633	0.637	0.641	0.645	0.649	57	77	4.331	4.390	4.449	4.511	4.574	4.638	4.705	12
33	0.649	0.654	0.658	0.662	0.666	0.670	0.675	56	78	4.705	4.773	4.843	4.915	4.989	5.066	5.145	11
34	0.675	0.679	0.683	0.687	0.692	0.969	0.700	55	79	5.145	5.226	5.309	5.396	5.485	5.576	5.671	10
35	0.700	0.705	0.709	0.713	0.718	0.722	0.727	54	80	5.671	5.769	5.871	5.976	6.084	6.197	6.314	9
36	0.727	0.731	0.735	0.740	0.744	0.749	0.754	53	81	6.314	6.435	6.561	6.691	6.827	6.968	7.115	8
37	0.754	0.758	0.763	0.767	0.772	0.777	0.781	52	82	7.115	7.269	7.429	7.596	7.770	7.953	8.144	7
38	0.781	0.786	0.791	0.795	0.800	0.805	0.810	51	83	8.144	8.345	8.565	8.777	9.010	9.255	9.514	6
39	0.810	0.815	0.819	0.824	0.829	0.834	0.839	50	84	9.514	9.788	10.08	10.39	10.71	11.36	11.43	5
40	0.839	0.844	0.849	0.854	0.859	0.864	0.869	49	85	11.43	11.83	12.25	12.71	13.20	13.73	14.30	4
41	0 869	0.874	0.880	0.885	0.800	0.895	0.900	48	86	14.30	14.92	15.60	16.35	17.17	18.07	19.08	3
42	0.900	0.906	0.911	0.916	0.922	0.927	0.933	47	87	19.08	20.21	21.47	22.90	24.54	26.43	28.64	2
43	0.933	0.938	0.943	0.949	0.955	0.960	0.966	46	88	28.64	31.24	34.37	38.19	42.96	49.10	57.29	1
44	0.966	0.971	0.977	0.983	0.988	0.994	1.000	45	89	57.29	68.75	85.94	114.6	171.9	343.8		
Degrees.	60′	50′	40′	30′	20′	10′	0′	Degrees.	Degrees.	60′	50′	40′	30′	20′	10′	0′	Degrees.
	COTANGENT.									COTANGENT.							

Examples.

To cut a miller with spiral teeth at an inclination of 20°. Diameter of cutter $= 1\,{}^1/_4$ inch $t = 40$. $g = 1$. $s = 4$.

$$a = 3\,.\,14 \times 1\,{}^1/_4 = 3{,}925 \text{ inch.}$$

$$\text{Cotan. } B = 2{,}747.$$

$$b = a \text{ cotan. } B = 3{,}925 \times 2{,}747 = 10{,}781975 \text{ inch}$$

$$\text{or } \infty\, 10\,{}^3/_4 \text{ inch.}$$

According to (11), the constant $c = \frac{t}{g.\,s.} = 10$.

$$X = 10\tfrac{3}{4}.$$

$$\frac{a}{b} = \frac{X}{c} = \frac{10\frac{3}{4}}{10} = \frac{43}{40}.$$

The gear on the worm must, consequently, have 43 teeth, that on the feed screw of the table having 40, an idle gear chosen at will is used and the table set at an angle of 20°.

A right hand cutter will be the result, provided, of course, that the feed screw has a right hand thread, which is almost always the case. Should a left hand cutter be required, a second idle gear must be engaged.

(2) Diameter of cutter = 3 inch, the lead of the spiral being 9 times the diameter.

$$t = 60. \quad g = 1. \quad s = 4. \quad v = 23.$$

$$a = 3\,.\,14 \times 3 = 9{,}42 \text{ inch.}$$

$$b = 9 \times 3 = 27.$$

$$tg\,B = \frac{a}{b} = \frac{9{,}42}{27} = 0.348.$$

The table shows that $tg\,19^0\,10' = 0.348$. $\angle$ B is thus $19^0\,10'$, at which angle the table must be set.

$$X = 27 \text{ inches.}$$

$$c = \frac{t}{g.\,s.} = \frac{60}{4} = 15.$$

$$\frac{X}{c} = \frac{a}{b} = \frac{27}{15} = \frac{54}{30} = \frac{2 \times 27}{2 \times 15} = \frac{40 \times 27}{30 \times 20}.$$

(3) Diameter of cutter 3 inches; length of spiral 27 inches.

$$t = 80. \quad g = 2. \quad s = 4.$$

$$a = 3\,\pi. \quad b = 27.$$

$$tg\,\mathrm{B} = \frac{a}{b} = \frac{3\pi}{27} = \frac{1}{9}\pi = 0.349.$$

$$tg\ 17^{\circ}\,10' = 0.348$$

$$c = \frac{t}{g\,s} = \frac{80}{2 \times 4} = 10.$$

$$\frac{\mathrm{X}}{c} = \frac{a}{b} = \frac{27}{10} = \frac{3 \times 9}{2 \times 5} = \frac{30 \times 45}{20 \times 25}.$$

According to table I, page 58, this cutter should have from 22 to 23 teeth.

$$n = \frac{t}{g\,v} = \frac{80}{2 \times 22} = \frac{80}{44}. \quad n = h + \frac{q}{p} = 1\,\frac{18}{22}.$$

In table XVI for diameters up to 4 inches and for a lead of spiral of 100 inches, the angle at which the table must be placed is to be found by going through the columns horizontally and vertically till they meet one another. The backing-off of cutters, although really forming part of this chapter, will be treated separately later on.

i. THE HARDENING OF CUTTERS.

The hardening of cutters forms part of the various operations which the blank must undergo before being fit for use but which can only take place when the mechanical treatment is as good as over and it is just this operation or treatment which may be regarded as one of the most dangerous since it is during this process that the cutter runs the greatest risk of being entirely spoiled.

The process of hardening may be briefly described as: *bringing the workpiece up to a certain temperature and then quenching it quickly.* By this means the steel changes to a state in which it can no longer be machined by other steel tools.

From the foregoing definition of the hardening process, the following questions arise:—

1. How is this heating to be effected?
2. To what temperature must the cutter be heated?
3. How should the metal be quenched?

Table XVI. — Table giving the angle in degrees for setting the milling table.

Lead of spiral.	DIAMETER OF CUTTER IN INCHES.																			
	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/4	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
inches.																				
1	21.3	38.1	49.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 1/8	19.3	35	46.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 1/4	18	33	43.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 1/2	12.4	25	35.2	43	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 7/8	11.4	22.4	32.2	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	10.3	21.3	30	37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2 1/4	10	19.2	27.4	35	41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2 1/2	9	17.3	25.2	32.2	38.2	43.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2 7/8	8	15.3	22.4	29.2	35	40	44.2	—	—	—	—	—	—	—	—	—	—	—	—	—
3	7.3	14.4	21.3	27.4	33.2	38.2	42.3	—	—	—	—	—	—	—	—	—	—	—	—	—
3 1/2	6.3	13	19.2	25	30	35	39	43	—	—	—	—	—	—	—	—	—	—	—	—
3 3/4	6	11.2	17.3	22.4	27.4	32.2	36.2	40	—	—	—	—	—	—	—	—	—	—	—	—
4	5.3	11	16.3	21.3	26.3	30.3	34.3	38.2	44.3	—	—	—	—	—	—	—	—	—	—	—
4 1/2	5	10	14.4	19.2	23.3	27.5	31.3	35	41	—	—	—	—	—	—	—	—	—	—	—
4 3/4	4.5	9.2	14	18.2	22.3	26.3	30	33.3	39.3	44.4	—	—	—	—	—	—	—	—	—	—
5	4.3	9	13.3	17.3	21.3	25.3	28.4	32.3	38.2	43.2	—	—	—	—	—	—	—	—	—	—
6	3.5	7.3	11	14.4	18.2	21.3	24.3	27.4	33.2	37.3	42.3	—	—	—	—	—	—	—	—	—
6 1/2	3.3	6.3	10.2	13.3	16.4	19.4	22.4	25.3	30.4	35.3	40	43.3	—	—	—	—	—	—	—	—
7	3.2	6.2	9.2	12.2	15.2	18	21	23.3	28.4	33.3	37.3	41.2	—	—	—	—	—	—	—	—
7 1/2	3	6	9	11.4	14.4	17.3	20.2	22.4	27.4	32.2	36.2	40	43.2	—	—	—	—	—	—	—

11	2	4	6	8	10	12	14	15.4	19.3	23	26.2	29.3	32.3	35.2	37.4	40.2	42.3	—	—	—
12	1.5	3.5	5.3	7.3	9.2	11	13	14.4	18	21.3	24.3	27.4	30.3	33.2	35.4	38.2	40.3	42.3	44.3	—
13	1.4	3.2	5	6.5	8.3	10	11.4	13.2	16.3	19.3	22.3	25.2	28	30.3	33	35.2	37.3	39.3	41.3	43.2
14	1.4	3.1	4.5	6.3	8	9.4	11.2	12.4	15.5	18.4	21.3	24.2	27	29.3	32	34.2	36	38	40	42
15	1.3	3	4.3	6	7.3	9	10.3	11.4	14.4	17.3	20.4	22.4	25.2	27.4	30	32.2	34.2	36.2	38.2	40
16	1.3	2.5	4.1	5.3	7	8.3	9.4	11	13.4	16.3	19	21.3	23.4	26.2	28.2	30.2	32.3	34.3	36.2	38.4
18	1.2	2.3	3.5	5	6.2	7.3	8.4	10	12.2	14.4	17	19.2	21.3	23.3	25.4	27.4	30	32	33	35
20	1.1	2.2	3.2	4.3	5.3	6.4	7.4	9	11	13.2	15.2	17.3	19.3	21.3	23.2	25.2	27	28.4	30.3	32.2
22	1	2	3	4	5	6	7	8	10	12	14	15.4	17.4	19.3	21.2	23	24.4	26.2	28	29.3
24	1	1.5	2.5	3.5	4.5	5.3	6.3	7.3	9.2	11.2	13	14.4	16.3	18.2	19.4	21.3	23	24.4	26.2	27.4
25	1	1.5	2.4	3.3	4.3	5.2	6.2	7.2	9	10.4	12.3	14	15.4	17.3	19	20.4	22.2	23.4	25.5	26.4
27	0.5	1.4	2.3	3.2	4.2	5	6	6.4	8.3	10	11.4	13.2	14.4	16.3	18	19.3	21	22.3	23.4	25.2
30	0.5	1.3	2.1	3	3.5	4.3	5.2	6	7.3	9	10.3	12	13.3	14.4	16	17.3	18.4	20	21.3	22.4
32	0.4	1.3	2	2.5	3.3	4.2	5	5.3	7	8.3	9.4	11	12.3	13.4	15	16.3	17.4	19	20.2	21.3
36	0.4	1.2	2	2.3	3.2	3.2	4.3	5	6.2	7.3	8.4	10	11.2	12.3	13.4	14.4	16	17.2	18.2	19.3
40	0.3	1.1	1.4	2.1	2.5	3.2	4	4.3	5.3	6.4	7.4	9	10	11	12.2	13.2	14.2	15.3	16.3	17.3
44	0.3	1	1.3	2	2.3	3	3.3	4	5	6	7	8	9	10	11	12	13	14	14.4	15.4
48	0.3	1	1.3	2	2.2	2.5	3.2	3.4	4.4	5.4	6.3	7.3	8.2	9.2	10	11	12	13	13.4	14.4
50	0.3	1	1.2	1.5	2.2	2.4	3.1	3.3	4.3	5.3	6.2	7.2	8	9	9.4	10.4	11.3	12.3	13.2	14
60	0.3	0.5	1.1	1.3	2	2.2	2.4	3	3.3	4.3	5.2	6	6.4	7.2	7.4	8.2	9	9.4	10.3	11.2
70	0.2	0.4	1	1.2	1.3	2	2.2	2.3	3.2	3.4	4.3	5	5.4	6.2	7	7.3	8.2	8.4	9.3	10
80	0.2	0.3	0.5	1.1	1.3	1.4	2	2.2	2.4	3.3	4	4.3	5	5.3	6.2	6.4	7.2	7.4	8.2	9
90	0.2	0.3	0.4	1	1.2	1.3	1.4	2	2.3	3	3.3	4	4.3	5	5.3	6	6.3	7	7.3	8
100	0.2	0.3	0.4	1	1.1	1.2	1.3	1.4	2.2	2.4	3.2	3.3	4	4.3	5	5.3	5.4	6.2	6.4	7.2

The figures following the comma indicate the sixths of a degree, e. g. 19, 3 means 19° 30′.

Heating. The cutter should be heated as gradually as possible. The heating of the outside takes place first, the external parts transferring the heat to the internal parts through the metal.

From this point of view it would appear that the heating should be effected very slowly were it not that for other reasons it is preferable to effect the heating as quickly as possible, the principal reason being that when red-hot, the carbon of the steel unites with the oxygen of the atmosphere forming oxyd of carbon which renders the quality of the steel inferior. The longer, therefore, the cutter remains red-hot, the longer this chemical process continues, the more the carbon is abstracted from the external layers of the cutter which are just the very parts required for cutting.

It is for this reason that the grinding of cutters *after* hardening has proved such a great improvement since the the external edges of the teeth, which are the first to be heated and are heated the most, thus suffering the greatest loss of carbon, are ground off.

The ordinary forge *fails entirely* to comply with the two foregoing conditions, viz:—the gradual heating of every part and the preservation of the carbon in the steel.

The fire in the open forge is raised to a certain temperature and maintained at that temperature by forced draught which, however, occurs only at a fixed point so that it is impossible to expose every part of the cutter to the same heat. Attempts are sometimes made to surmount this difficulty by constructing a small oven of fire-bricks over the fire, but, nevertheless, it is impossible to prevent the underside of the cutter being exposed to a higher temperature than the upper part and sides. Moreover, whether the cutter is heated in a fire which is fully open or in a space above the fire so as to prevent the heat spreading too rapidly through the surrounding atmosphere, the fact remains that the temperature has to be maintained by forced draught, i. e. oxygen, which is just one of the obstacles that has to be contended against in the hardening process.

Another detrimental factor to be taken into account when heating in an open fire is the *fuel* and it should be noted that in this respect the workmen are themselves much to blame since if ordinary coals be employed the sulphur is released and if this unites with the steel, the result will be soft patches which completely spoil the cutter.

For lack of better means of heating recourse must be had to the open fire but in this case charcoal should be employed to heat the cutter since charcoal contains but little sulphur and further because charcoal requires but little draught to maintain its temperature with the result that there is less oxydation during the heating. Should charcoal be unobtainable, then cokes should be used but should the use of coal be imperative, the coal should first be burned dead to permit of the sulphur from the coal being consumed before putting the cutter in the fire.

When the fire has been raised to a sufficient temperature, a plate of adequate thickness should be placed over the fire and heated to a red-heat, after which the cutter should be placed on it. By this means, the forced air is prevented as far as possible from coming into direct contact with the cutter. If charcoal be employed, the cutter should be entirely covered with it which will also prevent, as far as possible, the surrounding air from coming into contact with the cutter, the same treatment being observed should cokes be used. If a long cutter, of not too large diameter, is to be hardened, it should be put into a gaspipe which should constantly be kept revolving in the fire.

The only means of ensuring that the quality of the steel will not have deteriorated after the hardening, is to take care, first of all, that the surface of the steel shall not be exposed to the influence of the oxygen from the atmosphere, secondly, that the surface of the steel does not come into contact with whatever fuel may be employed, and lastly, that the rise in temperature is spread gradually over every part of the steel.

The foregoing can only be obtained by the use of a proper heating furnace, a suitable type of which is illustrated on page 80, fig. 125.

Ordinary coal is burned in this type of furnace; the whole muffler being surrounded by the flames on all sides, the heating thus being perfectly even and regular. The cutter is placed in the muffler, the opening of which is first closed up with a fire brick, after which it is made air-tight by a close-fitting flap. Other furnaces are those heated by means of gas, the only difference in this case being the heating medium employed, the actual process remaining precisely the same. Of late, electric hardening furnaces have been placed on the market, which, on account of the perfect regulation of the temperature which they ensure, are highly recommendable.

Besides the hardening furnace there is still another method of raising the temperature of the cutter to be hardened whilst avoiding all injurious influences, viz:—heating in a salt bath.

By bringing the cutter up to the requisite temperature in a salt bath, it is safe-guarded against the risk of being overheated, which is a matter of primary importance.

The melting point of salt is about 750^{0} Celsius, and when heated above 900^{0} Celsius, the bath begins to boil, this being a temperature which is not at all injurious to the cutter. Moreover, seeing that the cutter is completely immersed in the bath, it is fully protected from the influence of the oxygen.

The salt is placed in a crucible, the bottom of which is first covered with soda, and it can, if desired, be heated on an open fire.

To obtain a thoroughly good mixture, a little potash or chrome-acid may be added. As it impossible to prevent the temperature being highest at the bottom of the mixture when the crucible is heated from underneath, it is advisible not to place the cutter at the bottom of the crucible but to suspend it in the molten mass by means of an iron hook. It is further advisible to warm the cutter slightly before introducing it in the mixture, but above all, care should be taken to see that the cutter is perfectly dry.

The heating of a cutter to the exact temperature simply demands practice. The cutter should be looked at from a dark place, at any rate not in broad daylight where it would be impossible to distinguish the exact colour of the steel. For this reason, the foregoing method of heating the cutter in a salt bath is highly recommended, whilst, nowadays the pyrometer is also largely used for reading the temperature in degrees.

The temperature to which the cutter should be raised depends to a certain extent on the brand of the steel; various tests have demonstrated that for fine quality tool steel this temperature varies from 900^0 to 1100^0 Celsius. The withdrawal of the cutter from the hardening furnace or salt bath for the purpose of ascertaining the temperature, cannot but exercise a deletrious effect on the hardening process owing to the risk of oxydation to which the cutter is then exposed.

Quenching. If it is possible to spoil the cutter, the making of which has entailed so much work, during the heating, in spite of the exercise of the utmost care, still more care and attention are required as well as a great deal more regular practice, to ensure a proper quenching.

The best liquid for quenching is either snow or rain-water. At any rate, it must possess good heat-conducting properties, for which reason the water must be soft. Should the water contain lye or carbonic acid lime, these will be deposited on the surface of the cutter and impede the quenching. For this reason it is advisible not to use spring water; should neither snow nor rain-water be obtainable, then running water should be used. If nothing but spring water is obtainable, it is advisible to boil it first, or better still, to distil it. To increase the heat-conducting properties of the water, a little sulphuric acid or brine, salt or amonia should be added to the bath. The water should not be too cold, from 20^0 tot 25^0 Celsius being a suitable temperature. Cold water hardens quicker but makes the outer surface too brittle. If the cutter to be hardened is not required for machining hard metals so that extreme hardness is not necessary, warmer water may be used; even at the boiling point of 100° Celsius, the water will not have lost its quenching properties.

The hardening bath should be close to the spot where the cutter is heated, firstly, to prevent a diminution of the temperature of the cutter whilst being carried to the bath, and secondly, to prevent oxydation. The cutter must not be taken hold of with cold tongs, nor on any account by the teeth. The surface of the teeth, must not be covered. Shell cutters, which from their form are difficult to take hold of, should be plunged in the liquid by means of an iron hook which has previously been put through the bore; on no account whatever may the cutter be allowed to fall into the liquid. The quantity of liquid into which the cutter is plunged, must be sufficient to ensure the temperature remaining constant during the quenching. When the cutter has been submerged, it must be kept moving to and fro, as during the quenching steam is generated and bubbles will adhere to the surface of the cutter and prevent the quenching being perfectly even.

A cutter with hard but tough teeth and soft core is obtained by plunging the cutter into pure and rather cold water for a moment and then, as soon as the teeth have cooled sufficiently, taking the cutter out of the water quickly and completing the quenching in oil. The time during which the cutter should be kept in the water depends on its size.

Another method of hardening which also produces excellent results consists in carrying out the hardening under a jet of water. For this purpose, the whole breadth of the cutter must be covered by the jet and to effect this successfully, considerable practice is necessary.

Before removing the cutter from the cooling liquid, care must be taken to ensure that it is entirely quenched, internally as well as externally. Cutters of large dimensions require some considerable time before this is properly effected; cutters of even 10 and 6 inches diameter which had been set in a draughty place after insufficient quenching (notwithstanding that the exterior surface was quite cold), have been known to spring in two or more pieces with a loud report.

The manner in which the cutter should be plunged into the liquid depends entirely on its form and must be left to the experience of the workman; a thin, flat cutter being submerged on its side, a long cutter of small diameter being put in vertically to the direction of its axis.

As far as possible the cutter should be hardened in such a manner that it will at once acquire the required hardness, so as to avoid the necessity of tempering. The following further particulars are given with a view to ensuring any possible tempering being carried out property, rather than to encourage same, since a cutter which has received proper treatment up to and including its hardening, may still be spoiled by tempering. For this purpose, i. e. tempering, a thin, flat cutter may be placed on a plate heated over a charcoal fire, a long cutter of small diameter being placed in a heated gaspipe though a sand bath is far preferable as in the latter case every part of the cutter is exposed to a perfectly even temperature; cutters, the diameters of which are not too large and which have a bore, may be tempered by mounting them on a heated arbor, taking care, however, that this fits exactly. Care must also be taken beforehand that the teeth are scraped clean at various places to permit of the exact increase of colour being observed, whilst the tempering must proceed regularly though not too quickly. A cessation of the tempering will give no further assurance that the increase of colour will indicate the precise degree of hardness of the steel.

Formerly, and even at the present day, the process of hardening was regarded as more or less of a mystery, full of secret tricks known only to a few of the initiated. *It cannot, however be too strongly insisted upon that such an idea is wholly erroneous.* The methods of heating and quenching are simplicity itself. The workman who has to perform the work, has simply to know what he has to do, must have the necessary means at hand and last but not least, have a clear idea as to what actually takes place during the hardening process. It is, of course, advisible to let the same person carry out the hardening work since, as in work of every kind, practical experience will save him from making mistakes. The principal thing to bear in mind is a regular, rational, and, at the same time quick increase of temperature, carefully avoiding all injurious influences, raising the cutter to the exact temperature and good quenching.

CHAPTER VII.

Speed and Feed of Cutters.

With the cutter as with every other rotary cutting tool, two different motions in operation at the same time have to be taken into consideration.

First there is the rotary movement of the tool by which the metal is removed. The principle contained in the milling cutter, viz: the circular cutting tool, the contour being provided with teeth which cut into the work successively and, after having completed part of a revolution, are again disengaged, being succeeded in their turn by other teeth, clearly indicates that with regard to this motion, it is the workpiece that remains stationary whilst the cutter rotates.

It is this movement which is meant by the term "*cutting speed*", i. e. the distance in a straight line traversed by a certain point on the circumference of the cutter per unit of time, as for instance, per second.

It is evident that the cutting speed can be obtained by multiplying the number of revolutions completed by the cutter in a given unit of time by the circumference of the cutter.

The second movement is that by which the workpiece is carried along a certain point on the cutter or visa versa. This movement can be either in a straight line, circular or in a curved line and is termed the *feed*. This motion should be expressed as the feed in a straight line per unit of time so that in accordance with the tensity of the metal, the quality of the cutter, and the construction of the machine, the rate of speed and the rate of feed may be determined independent of each other. The present construction of so many milling machines leaves much to be desired in this respect since the rate of feed is dependent on the number of revolutions of the cutter and is consequently expressed by a certain length per revolution of the cutter. Now the possibility is not at all excluded that, for instance, a coarse feed should be desired with a cutter of large diameter whilst a fine feed is required with a small diameter cutter. The feed is, however, dependent on the number of revolutions of the cutter. The only thing possible in such a case is to choose the largest possible feed for the large cutter and the smallest possible feed for the small cutter. Notwithstanding this, it will still be quite possible that even the coarsest feed will still be too slow, whilst with the slowest feed, it will be too coarse.

Until quite recently the feed mechanism was driven by a three-step cone pulley on the main spindle of the milling machine, corresponding to an identical pulley on the feed shaft. These cone pulleys were made unequal in diameter so that, if required, they could be changed. By this means 3 i. e. 6 different rates of feed were obtainable for each speed of the main spindle.

Of late, however, (and this has generally been adopted by all American makers of any importance), the feed is no longer operated by a cone pulley but by means of positive drive from the main spindle whilst by means of a gear box, as many as 16 different positive rates of feed have been obtained, which are, however, still dependent on the speed at which the cutter rotates.

Some of the latest constructions, namely those of Brown & Sharpe, Kearney & Trecker and the Cincinnati Milling Machine C°., introduce a great improvement in this respect. The different speeds at which the cutter rotates are no longer obtained by means of a cone pulley but by means of a gearing between the main spindle and a pulley of large diameter rotating at a constant rate of speed. The feed is driven from a shaft also running at a constant speed *and is consequently no longer dependent on the speed of the cutter.* The ideal method would, however, be that the feed should be driven by a seperate countershaft entirely independent of the machine. This however involves some other difficulties which up till now have not been surmounted.

The speed at which the tooth of the cutter can move through the material is chiefly dependent on the hardness on softness of metal to be machined and the quality of the cutter, always presuming that the cutter itself is well made and constructed and that the construction of the machine permits a reasonable rate of speed.

Fixed rules, holding good for every case, cannot be laid down with regard to the cutting speed, which can only be determined according to circumstances which are themselves very divergent. In general, factories which make the manufacture of cutters a speciality, give the following figures for the number of revolutions per minute.

$$\left.\begin{array}{ll} \left. n=\dfrac{200}{\text{diam. of cutter in inches}} \right\} & \begin{array}{c}\text{for soft tool steel}\\ \text{and cast iron.}\end{array} \\[2ex] \left. n=\dfrac{200-240}{\text{diam. of cutter in inches}} \right\} & \begin{array}{c}\text{for forgings and}\\ \text{steel.}\end{array} \\[2ex] \left. n=\dfrac{320-400}{\text{diam. of cutter in inches}} \right\} & \text{for brass.} \end{array}\right\} \begin{array}{c}\text{for cutters}\\ \text{made of}\\ \text{ordinary}\\ \text{tool steel.}\end{array}$$

Given that $n =$ No. of revolutions per minute.

D = Diameter of cutter in inches.

V = surface speed in feet per minute.

then

$$\begin{array}{ccc} \text{for soft tool steel and cast iron.} & \text{for forgings and steel.} & \text{for brass.} \\ n=\dfrac{200}{D} & n=\dfrac{200-240}{D} & n=\dfrac{320-400}{D} \end{array}$$

$$V=\frac{\pi D n}{12}.$$

D n is the constant value present in the numbers 200, 200—240, and 320—400 so that we can thus write:—

$V = \frac{\pi\,200}{12} = 52$ feet per minute for soft tool steel and cast iron.

$V = \frac{\pi\,200-240}{12} = 52-58$ feet per minute for forgings and steel.

$V = \frac{\pi\,320-400}{12} = 84-100$ feet per minute for brass.

The surface speed V for cutters of high speed steel is naturally higher and we find fairly divergent numbers, amongst others:—

1. Weber.

Cast iron and tool steel	83—125	feet.
Steel	100—133	„
Wrought iron	150—200	„
Brass	200—250	„

2. Bonner Milling Cutter Works.

Tough steel	66	„
Medium tough steel.	100	„
Brass	200	„

3. The Cincinnati Milling Company.

Cast iron	40	„
Steel	80	„
Brass	122	„

4. Ludw. Loewe.

Cast iron	83—125	„
Tool steel	100—133	„
Wrought iron	150—200	„
Brass	233—265	„

The figures most divergent are met with under 3 and 4.

Cast iron	40—125	„
Steel	80—133	„
Brass	122—265	„

Differences thus of from 100—200 %. The reason of this is that in the data given by Loewe only the surface speed which can be imparted to the cutter as a maximum under the most favourable conditions has been taken into consideration. The Cincinnati Milling Company give the speed according to the number of revolutions at which the milling machine can run under variable conditions, including the less favourable ones. As a general average the figures given under 2 can be taken.

Although as explained above there are no fixed rules relative to the surface speed of cutters, the data given above may be generally accepted, since they have been laid down as possible by manufacturers who may be regarded as authorities on the subject. For the rest, practical experience must decide each case separately. Tables XVII and XVIII give the surface speed and rate of feed for cutters made of ordinary and high speed steel.

TABLE OF AVERAGE CUTTING SPEEDS FOR CUTTERS MADE OF ORDINARY TOOL STEEL.

Table XVII.

	Cast iron.	Steel and forgings.	Brass.	Cast iron.	Steel and forgings.	Brass.	Cast iron.	Steel and forgings.	Brass.
Surface speed in feet per min.	40	50	90	48	56	100	56	62	110
Constant per min. Diam. of cutter in inches.	$\frac{150}{D}$	$\frac{190}{D}$	$\frac{340}{D}$	$\frac{180}{D}$	$\frac{210}{D}$	$\frac{380}{D}$	$\frac{210}{D}$	$\frac{235}{D}$	$\frac{420}{D}$
NO: OF REVOLUTIONS PER MINUTE.									
Diameter of cutter in inches.									
1	150	190	340	183	210	380	210	237	420
$1^3/_{16}$	127	160	285	153	178	320	178	197	350
$1^3/_8$	110	137	245	130	153	273	153	160	300
$1^5/_8$	95	120	215	114	134	238	134	148	262
2	77	95	172	91	107	190	107	118	201
$2^3/_8$	63	80	143	76	89	160	89	98	175
$2^3/_4$	55	68	122	65	76	136	76	84	150
$3^1/_4$	48	60	107	57	67	110	67	74	131
$3^1/_2$	42	53	95	51	59	106	59	66	116
4	38	48	86	46	53	95	53	59	105
$4^1/_4$	35	43	78	42	48	87	48	54	95
$4^3/_4$	32	40	71	38	44	80	44	49	87
$5^1/_4$	29	37	66	35	41	73	41	45	81
$5^5/_8$	27	34	61	32	38	68	38	42	75
6	25	32	57	30	35	63	35	39	70
$6^1/_4$	24	30	53	28	33	59	33	37	65
7	21	26	47	25	30	53	30	33	58
8	19	24	43	23	27	48	27	29	52
9	17	22	39	21	24	42	24	27	47
10	15	19	34	18	21	38	21	23	42
Feed in inches per min.	$^3/_8$-1	$^5/_8$-$1^1/_4$	$1^1/_2$-$2^1/_2$	$^5/_8$-$1^1/_4$	$^7/_8$-$1^3/_4$	$2^1/_2$-$3^1/_2$	$^3/_4$-2	$1^1/_4$-$2^1/_2$	3-5

THESE SPEEDS ARE SUITABLE FOR THE FOLLOWING CUTTERS:

Gear cutters.	Module 10—12.	Module 6—9.	Module 1—5.
Keyway cutters.	4—10 inch diam.	3—6 inch diam.	$1^1/_2$—4 inch diam.
Angle cutters.	5—10 „ „	3—4 „ „	$1^1/_2$—3 „ „
Shell cutters.	4— 8 „ „	$2^1/_2$—5 „ „	$1^1/_2$—3 „ „
Shell and end cutters.	Up to 12 inch length, up to 2 inch diam.	Up to 6 inch length.	Up to 4 inch length.

AVERAGE CUTTING SPEED FOR CUTTERS OF HIGH SPEED STEEL.

Table XVIII.

	Tough steel.	Medium tough steel.	Brass.
Surface speed in feet per minute.	66	100	200
Revolutions per minute = $\frac{\text{Constant per min.}}{\text{Diam. of cutter in inches.}}$	$\frac{250}{D}$	$\frac{390}{D}$	$\frac{780}{D}$

NO. OF REVOLUTIONS PER MINUTE.

Diameter of cutter in inches.	1	256	392	784
	$1^3/_{16}$	218	327	653
	$1^5/_8$	160	245	490
	2	128	196	392
	$2^3/_8$	107	163	327
	$2^3/_4$	91	140	280
	$3^1/_4$	30	123	245
	$3^1/_2$	71	109	218
	4	64	98	196
	$4^3/_4$	53	82	163
	$5^5/_8$	46	70	140
	$6^1/_4$	40	61	123
	7	36	54	109
	8	32	49	98
	9	29	45	89
	$9^1/_4$	26	39	78
Feed in inches per min.		$1^1/_2$—3	3—5	5—8

With the present construction of the milling machine it is impossible to obtain all these rates of speed and the surface speed given can only be approximately imparted to the cutter.

The number of speeds on the modern milling machine when using double back gear with two speed countershaft amounts to 16 and from this number the choice has to be made.

The following particulars are given as to the number of speeds possible with the Cincinnati milling machine and practically agree with those given by other makers:—

Table XIX.

Number of revolutions on the Cincinnati milling machines.

No.	0	1	1½	2	3	4
	—	—	12	10	9	6½
	—	—	17	14	13	9
	—	—	20	17	15	12
	—	—	24	21	19	14
	—	—	28	26	22	17
	—	—	34	32	30	21
	—	—	40	37	34	26
	—	—	59	56	51	40
	54	40	75	65	60	51
	82	64	106	96	88	76
	101	75	127	112	103	93
	126	100	150	141	133	115
	154	120	180	166	150	138
	202	160	218	211	203	172
	236	187	255	243	230	210
	378	300	370	365	350	312

Only the number of revolutions given under the respective numbers can thus be obtained on each machine. These speeds can only be proportionately reduced or increased when absolutely necessary for the work in hand, by changing the speed of the countershaft.

With motordriven machines the conditions are much more favourable. A rheostat can then be introduced for variable speeds so that the number of revolutions of the motor can be regulated within the limits of 1 : 2 and in this manner the desired surface speed can actually be imparted to the cutter.

Although the proper surface speed of the cutter is of influence on the time required, when considering the output, the rate of feed is of much more importance.

Granted that the construction of the machine is such as enables it to execute what may be required of it, the rate of feed depends on the following conditions:—

1. The quality, construction and type of cutter.
2. The depth of cut and width of surface to be machined.
3. The resistance offered by the metal.
4. The degree of accuracy required in the workpiece.

The most important factors in this respect are:—the quality of the cutter, the depth of cut, and the resistance of the metal.

Fixed rules can no more be given for the rate of feed than for the cutting speed. In this case practical experience is everything. It is true that certain figures are given in the foregoing tables which may serve as starting points but it will have been noticed that differences of 100 % and more are given. The best advice that can be given in this connection is certainly that given by Reinecker when speaking of "Speeds and Feeds", viz:—"Start with a feed that is too slow and then increase the feed as far as the cutter, the machine and the workpiece will allow of it, not overlooking the quality of the surface which is being machined."

The rate of feed possible on the milling machine will be fully dealt with in the chapter treating of the construction of the milling machine.

The thickness of the chip can be calculated by dividing the feed per revolution of the cutter by the number of teeth of the cutter. With a feed of 1/4 inch per revolution of the cutter, (one of the quickest possible feeds on the newest type of milling machine), and a cutter with 25 teeth, a chip is obtained having a thickness of $\frac{1/4}{25} = 0{,}01$ inch for each tooth which, in comparison with other cutting tools, as for instance the lathe tool which nowadays works with a thickness of chip up to $^1/_8$ inch, is certainly very small. However, no quicker feed average is adopted than 0,05 inch per revolution of the cutter, whilst it is often much less and in this case with a cutter with 20 teeth the chip will have a thickness of $\frac{0{,}05}{20} = 0{,}0025$ inch.

It is only possible to comply with all demands with reference to cutting speed and rate of feed, when the cutting speed can be regulated according to the metal to be cut, and further when the feed can be regulated according to circumstances entirely apart from the cutting speed so that *the proper speed is obtainable by the desired feed.* With the milling machine with cone drive, this is an impossibility as will be clearly shown in the chapter dealing with construction of milling machines. This is possible with a machine which is specially constructed for a particular purpose, since the workpiece and the cutter to be used are taken into consideration in constructing the machine.

The following examples taken from actual practice will serve as points of comparison for others in their own work and will, at the same time clearly demonstrate that the rate of feed and cutting speed cannot be laid down on hard and fast lines nor can they always be so combined as could be desired.

It should further be remembered that all these examples are given to show, not how *slowly* but how *quickly* the work can be performed and should consequently be regarded in general as the maximum.

1. A cutter with inserted teeth, $4^1/_2$ inch diameter, cutting speed 40 feet per minute, takes a cut $^3/_{32}$ inch to $^1/_8$ inch deep from castings having a width of $8^1/_4$ inch, the

feed being .252 inch per turn of cutter which is equivalent to a table travel of $8^{1}/_{2}$ inch per minute.

A surface, $8^{1}/_{4}$ inch wide and $8^{1}/_{2}$ inch long, is consequently milled in 1 minute.

2. A composed cutter, with diameter varying from 5 inches to 3 inches, rotates at a speed of 31 revolutions per minute and with a feed of .075 inch equivalent to 2.325 inches per minute, removes about $^{1}/_{8}$ inch metal all around. Metal, cast iron. Total width of surface $11^{3}/_{4}$ inch.

3. Two sets of composed milling cutters, the larger having a diameter of $13^{1}/_{2}$ inches and milling the sides, make 12.5 revolutions, the surface speed being 40 feet per minute, the rate of feed .10 inch per revolution of the cutter, equivalent to $1^{1}/_{4}$ inch per minute.

4. A shell mill with spiral teeth, $2^{3}/_{4}$ inch diameter, takes a cut $2^{3}/_{4}$ inches wide and $^{1}/_{16}$ inch deep from the top and bottom of a workpiece $2^{3}/_{4}$ inches wide with a feed of 3 inches per minute. Metal: cast iron.

5. A shell cutter with spiral teeth, $4^{1}/_{2}$ inches diameter and 6 inches face having a surface speed of 47 feet per minute takes a cut of $^{3}/_{32}$ inch from a piece 10 inches wide with a feed of .076 inch per turn of the cutter, equivalent to 3 inches per minute. After this, the feed is reduced for the finishing cut to .036 inches per turn of the cutter, removing .010 inch. Metal: cast iron.

6. A face cutter with inserted teeth, 8 inches diameter takes a cut of $^{1}/_{8}$ inch deep in cast iron at a feed of 1.025 inch per turn of cutter.

7. An end mill with spiral teeth, $1^{5}/_{8}$ diameter, cuts a rectangular slot of the same width $1^{1}/_{8}$ inch deep with a feed of 1 inch per minute; surface speed 36 feet per minute; feed .012 inch per revolution of the cutter. Metal: cast steel.

8. A face cutter with inserted teeth, 8 inches in diameter makes 19 revolutions per minute, equivalent to a surface speed of 40 feet per minute, the feed being .138 inch per revolution of the cutter, equivalent to a table travel of 2.63 inches per minute, cuts away $^1/_8$ inch metal. The surface of the casting is 5$^7/_8$ inches wide. Metal: cast iron.

9. A shell mill with cast iron body and inserted teeth, 4$^1/_2$ inches diameter, makes 34 revolutions per minute, equivalent to a surface speed of 40 feet and, with a feed of .168 inch per revolution of the cutter, equivalent to a table travel of 5$^3/_4$ inches per minute, takes a cut in cast iron of $^3/_{32}$ inch deep and 6$^1/_2$ inch wide.

10. A face cutter of 4$^1/_2$ inches diameter, makes 51 revolutions per minute, which is 60 feet surface speed per minute, feed .252 inch per revolution of the cutter, equivalent to nearly 13 inches per minute. Depth and width of cut $^1/_{32}$ inch × 4$^3/_{16}$ inches; metal cast iron.

11. Two cutters, working with their front teeth and having a diameter of 4$^1/_2$ inches, make 34 revolutions per minute, which is a surface speed of 40 feet per minute. With a feed of .10 inch per revolution of the cutter, equivalent to 3.4 inches per minute, each of them takes a cut of $^3/_{32}$ inch. Thickness of the workpiece $^3/_4$ inch; metal cast iron.

12. A 6-fluted end mill cuts into solid cast iron bars 1 inch thick a slot of $^3/_4$ inch, wide, surface speed 72 feet per minute, feed .011 inch per turn of cutter, equivalent to 4 inches per minute.

13. 4 cutters on one arbor mill keyways, each $^1/_4$ inch wide, in 4 steel shafts placed side by side. Diameter of the cutters 2$^1/_2$ inches; no: of revolutions per minute 60; surface speed 40 feet per minute; feed .075 inch per turn of cutter, which is equal to a table travel of 4$^1/_2$ inches per minute.

14. Slots of $\frac{11}{16}$ inch width are milled in two pieces with backed-off cutters mounted on the same arbor. The metal is 40 carbon steel. Feed . 033 inch per minute equivalent to a table travel of 1 inch per minute.

15. A face cutter having a diameter of 6 inches makes 26 revolutions per minute, equivalent to 40 feet surface speed per minute, removing with a feed of . 20 inch per turn of cutter, equivalent to 5.2 inches per minute, $^1/_8$ inch metal. Width of casting $3^5/_8$; metal cast iron.

16. A spiral cutter, diameter 3 inches, makes 56 revolutions per minute, removing with a feed of . 05 inch per turn of cutter, equivalent to 2.8 inches per minute, $^3/_{64}$ inch metal. Width of surface is 5 inches; metal 90 carbon tool steel.

17. Two cutters of 5 inches diameter, work on the front faces at 32 revolutions per minute. With a feed . 05 inch per revolutions of the cutter, equivalent to 1.6 inch table travel per minute, each cutter removes about $^1/_8$ inch metal. Width of surface 2 inches; metal cast steel.

18. A shell cutter of $1^1/_2$ inch diameter makes 166 revolutions per minute, equivalent to 60 feet surface speed per minute and, with a feed of . 05 inch per revolution of the cutter, equivalent to 8.3 inch per minute, takes a cut of $^5/_8$ inch wide and removes $^1/_{16}$ inch of stock; metal 40 carbon drop-forged steel.

19. Two cutters on one arbor, the one an end cutter of 4 inches diameter and the other a shell mill of $2^1/_4$ inch diameter, make 112 revolutions per minute equivalent to a surface speed of 65 feet per minute of the shell cutter, and, with a feed of . 050 inch per revolution of the cutter, equivalent to a table travel of 5.6 inch per minute, take a cut of $1^7/_8$ inch wide removing $^1/_{16}$ inch of metal; metal 40 carbon drop-forged steel.

20. Two cutters on one spindle, $2\frac{1}{2}$ inches diameter, having a surface speed of 38 inches per minute, spline two shafts. Width of keyway $\frac{1}{4}$ inch; metal 40 carbon steel.

21. A composed cutter, the greatest diameter of which is $3\frac{1}{2}$ inches, makes 37 revolutions per minute feed .05 inch per turn of cutter, which is a table travel of 1.85 inch per minute; the width of the surface milled is $6\frac{1}{4}$ inches, removes $\frac{1}{8}$ inch metal all around; metal cast iron.

22. A gear cutter of 2 inches diameter works with a surface speed of 80 feet per minute and a feed of .10 inch per turn of cutter, equivalent to a table travel of 15.4 inches per minute. The cut is $\frac{5}{64}$ inch wide and $\frac{3}{32}$ inch deep: metal tool steel.

23. A composed formed cutter, milling partly on the contour and partly with the front faces, with diameters of $7\frac{1}{2}$, $5\frac{1}{2}$ and $3\frac{1}{2}$ inches, makes 28 revolutions per minute feed .063 inch per revolution of cutter, equivalent to a table travel of more than $1\frac{7}{8}$ inches per minute. The total width of the surface milled is 9 inches, the average depth of cut $\frac{1}{4}$ inch and the metal cast iron.

24. A face cutter with inserted teeth has a diameter of $10\frac{1}{2}$ inches and makes 17.5 revolutions per minute feed .300 inch per turn, equivalent to a table travel of $5\frac{1}{4}$ inches per minute. Total width of surface milled is 2 inches; depth of cut $\frac{1}{8}$ inch; metal cast iron.

25. A formed cutter mills cast iron racks 16 pitch in one cut. Diameter of cutter $2\frac{1}{2}$ inches, feed $\frac{3}{4}$ inch per minute. The teeth are $\frac{9}{16}$ inch deep and one rack is finished in 1 minute.

26. A cutter made of novo-steel works at a surface speed of 80 feet per minute and a feed of 2 inches per minute. The width of surface milled is $1\frac{3}{4}$ inch, the depth of cut $\frac{1}{2}$ inch—$\frac{3}{4}$ inch and the metal cast iron.

27. A composed cutter, working chiefly on the contour but also with the front faces, has a largest diameter of 6 inches, makes 33 revolutions per minute, feed 5 1/2 inches per minute. Width of surface milled 8 inches, removal 1/8 to 3/16 inch stock; metal cast iron.

28. A cutter, 2 1/2 inches diameter, making 34 revolutions per minute, feed .108 inch per revolution of the cutter, equivalent to 3 3/4 inches per minute, takes a cut from 1/8 to 3/16 inch deep and 2 3/4 inches wide. Metal cast iron.

29. A cutter of novo-steel having a diameter of 2 inches, makes 243 revolutions per minute, equivalent to a surface speed of 130 feet per minute. The feed is .150 inch per turn of cutter, equivalent to 36 inches per minute, and the metal cast iron.

30. A cutter of novo-steel is undercutting T slots. Diameter of cutter 1 inch by 1/2 inch face. No. of revolutions per minute 243, equivalent to a surface speed of 53 feet per minute. Feed .050 inch per revolution of the cutter, equivalent to 12 inches per minute.

31. A cutter, 3 1/2 inch diameter 3/8 inch face, mills a slot 1 inch deep in forged steel in one cut. No. of revolutions 56, feed per revolution of cutter .075 inch. A slot of 4 1/4 inches is thus milled per minute.

32. A shell cutter, 2 1/2 diameter, removes from casting 2 1/2 inches wide 1/8 to 3/16 inch metal. No. of revolutions per minute 46, feed .20 inch per revolution. A table travel of 9.2 inches per minute is consequently obtained.

33. A shell cutter, 3 inches diameter, making 56 revolutions per minute, feed .050 inch per revolution, equivalent to a table travel of 2.8 inches per minute, takes a cut 1/8 inch deep from cast iron pieces 6 5/8 inches wide.

34. A shell mill of 4 inch diameter makes 32 revolutions per minute cutting a slot $1^{13}/_{16}$ inch wide and $^{1}/_{2}$ inch deep in crucible steel. Feed .024 inch per revolution equivalent to .77 inch per minute.

35. An angle cutter mills the teeth of a spiral mill of novo-steel with coarse pitched teeth. This spiral mill, is to be provided with 12 teeth, .275 inch deep and $^{3}/_{4}$ inch wide on top. The angle cutter on the arbor has a diameter of $2^{1}/_{2}$ inches 80° including angle and makes 53 revolutions per minute; the feed being .042 inch per turn which is a table travel of nearly $2^{1}/_{4}$ inch per minute.

36. Two angle cutters side by side on the same arbor are milling the teeth of cast steel racks, two teeth being milled simultaneously. The cutters have a maximum diameter of $4^{1}/_{2}$ inches and a feed of .075 inch per revolution. The pitch is $^{7}/_{8}$ inch, depth of teeth $^{7}/_{16}$ inch.

37. A shell cutter of Novo steel having a diameter of $3^{1}/_{2}$ inch makes 90 revolutions per minute equivalent to a surface speed of 90 feet and with 3 inches face takes a cut varying from $^{1}/_{16}$ to $^{3}/_{32}$ inch, having a feed of 0.300 inch per revolution equivalent to 27 inches per minute. The metal being milled is cast iron.

38. Two composed cutter of $5^{3}/_{4}$ maximum diameter, milling square bars of 50 carbon steel make 20 revolutions per minute equivalent to a surface speed of 30 feet, the feed being $^{15}/_{16}$ inch per minute. The width of the surface milled is 9 inches with a depth of cut of $^{1}/_{4}$ inch.

39. A shell mill cuts cast iron plates 12 inches wide. The cutter, which has a diameter of 4 inches, makes 60 revolutions per minute with a feed of .075 inch per revolution which is a table travel of $4^{1}/_{2}$ inches per minute. The depth of cut is $^{1}/_{8}$ inch.

40. Subsequently, slots, having a total width of 6 1/2 inch have to be milled in these plates. The cutters which have a diameter of 4 inches make 60 revolutions per minute, the feed being .075 inch per revolution, making a table travel of 4 1/2 inches per minute.

Table XX in which all the foregoing examples have been set up, enables the reader to see at a glance the results which can be obtained on the milling machine under different conditions on diverse metals. Probably one or other of these examples can be used for purpose of comparison, in which case the manner in which the work is performed must not be lost sight of. The chapter dealing with actual performed work on the milling machine will treat of this point more again.

Tab

No. of example.	Kind of metal milled.	Diameter of cutter in inches.	Type of cutter.
1	Cast iron	4½	Shell cutter with inserted spiral te
2	" "	3	Shell cutter
3	" "	13½	Face cutter with inserted teeth
4	" "	2¾	Shell cutter
5	" "	4½	" "
6	" "	8	Face mill with inserted teeth
7	Crucible steel	1⅝	Shell cutter
8	Cast iron	8	Face mill with inserted teeth
9	" "	4½	Shell cutter with spiral teeth
10	" "	4½	End mill
11	" "	4½	Shell end mill
12	" "	1¾	End mill
13	Steel	2½	Shell cutter
14	"	6	End cutters
15	Cast iron	6	Face mill with inserted teeth
16	Crucible steel	3	Shell cutter
17	Cast steel	5	Shell end mill
18	" "	1½	Shell cutter
19	" "	2¼	" "
20	" "	2½	" "
21	Cast iron	5½	Shell end mill
22	Steel	2	Shell cutter
23	Cast iron	7½, 5⅜, 3⅝	Formed cutter
24	" "	10½	End mill
25	" "	—	Composed cutter
26	" "	5⅞—3⅞	Shell cutter
27	" "	2⅝	Shell cutter and face mill
28	" "	2	Shell cutter
29	" "	1	End mill
30	" "	3⅝	Shell cutter
31	Drop forged steel	2⅝	" "
32	Cast iron	3	" "
33	" "	3⅞	" "
34	Crucible steel	2⅜	" "
35	Novo-steel	4½	Angle cutter
36	Cast steel	3⅜	" "
37	Cast iron	2⅜	Shell cutter
38	Steel	5⅞	" "
39	Cast iron	3⅞	" "
40	" "	3⅞	" "

ner in which the cutter works.	No. of revolutions per min.	Surface speed in feet and inches per min.	Feed in inches per turn of cutter.	Feed in inches per min.	Depth cut in inches.	Width of surface milled in inches.
circumference	34	39′ 4 1/2″	1/4	8 1/2	1/8	8 1/4
„	41	23′ 7 3/4″	5/64	2 1/4	1/8	9 1/4
side surfaces	12.5	39′ 4 1/2″	7/64	1 1/4	—	—
circumference	—	—	—	3	1/8	2 3/4
„	38	47′ 3 1/2″	5/64	3	3/64	7 3/4
side surface	—	—	1/4	—	1/8	8
circumference	80	35′ 6″	1/64	1	1 5/22	1 3/8
side surface	19	39′ 4 1/2″	9/64	2 3/4	1/8	5 7/8
circumference	34	39′ 4 1/2″	11/64	5 3/4	3/32	6 1/2
side surface	51	59′ 3″	1/4	13 3/4	3/64	4 1/4
„ surfaces	34	39′ 4 1/2″	7/64	3 3/8	3/32	3/4
circumference	335	65′ 0″	1/64	1/2	3/4	1
„	60	39′ 4 1/2″	5/64	4 1/2	1/8	1/4
„	31	42′ 2 1/2″	1/32	1	13/16	1
side surface	26	39′ 4 1/2″	13/64	5 1/2	3/64	4
circumference	56	43′ 4″	0/64	2 3/4	1/16	5
side surfaces	32	42′ 3 1/4″	3/64	1 1/2	3/32	2 1/32
circumferences	116	57′ 3″	3/64	8 3/4	1/6	43/64
„	112	65′ 0″	3/64	5 1/2	1/6	2
„	134	37′ 2 1/4″	1/32	4 1/2	—	2 1/2
side surfaces	37	53′ 1 1/2″	3/64	1 7/8	1/8	6 1/4
circumference	156	78′ 9″	3/32	15 1/2	3/32	3/32
„	28	39′ 4 1/2″	1/16	1 3/4	17/64	9
„	17.5	48′ 4″	19/64	5 1/4	1/8	2
side surfaces	—	—	—	3/4	1/8	8
„ surface	—	78′ 9″	—	2	19/32	1 3/4
circumference	33	52′ 1″	11/64	5 1/2	13/64	13
„	34	22′ 7 3/4″	3/64	3 3/4	13/64	2 3/4
„	243	125′ 0″	9/64	36 1/4	—	—
„	243	54′ 2″	3/64	12	63/64	23/64
side surface	56	53′ 3″	3/64	4 3/8	63/64	25/64
circumference	46	30′ 7 1/2″	13/64	9 1/32	13/64	2 1/4
„	56	43′ 8″	7/64	2 2/4	3/64	6 3/4
„	32	28′ 6 1/4″	1/64	3/4	33/64	1 3/4
„	56	34′ 5 3/4″	1/32	1 7/8	9/32	51/64
„	—	—	1/64	—	7/16	1 3/4
„	90	79′ 9″	25/64	27	5/64	3
„	20	29′ 7″	3/64	1	19/64	9 1/2
„	60	61′ 10 1/2″	5/64	4 1/2	1/8	12
„	60	61′ 10 1/2″	1/32	1 1/2	—	6 1/4

PART II.

MILLING MACHINES.

CHAPTER VIII.

Construction of Milling Machines.

In the first part of the present work we discussed the milling cutter; we now come to the milling machine itself.

Seeing that the object of this work is to afford a general review of the milling machine, it goes without saying that a not inconsiderable portion should be devoted to the discription of the milling machine itself and for this reason this part of the work may be considered the principal containing, and we are here reviewing one of the finest types of machines employed in metal working.

Fruit of the modern development in the building of machine tools, the milling machine may be regarded as a minion, a tool to be constructed and reconstructed, which attracts to itself the attention of the finest intellects of this branch, in a word, a tool constructed first and foremost by the leading firms in which manufacture has been brought to the highest point of development.

In the same way that the milling cutter was developed in a comparatively short space of time in a manner that no other cutting tool has been developed, so also the milling machine, after once having taken its place in the general line of machine construction, has now been so universally adopted that its use far exceeds that of the greater number of other machine tools and it is now placed on the market in such a variety of constructions and applications, that an adequate description of the existing types of milling machines alone demands a far greater volume than would be required for a number of other types of machine tools together.

Does the milling machine owe its development to the milling cutter, or vice-versa? They are indissolably associated, the one with the other, still, one thing is certain, i. e. that milling machines in their present-day forms and constructions are a natural sequence of the need which existed for machines to carry out the work which could be executed with the milling cutter.

Although in the first part of the present work when considering milling cutters in general, we may, perhaps, having gone somewhat fully into the question of the development of the milling cutter, it would, however, carry us altogether too far to attempt to write the true history of the milling machine, however interesting such a theme might be. We shall thus confine ourselves to a general review of the milling machine as at present constructed, taking from time to time a glance at the infancy of this machine in order to afford the reader some idea of the difference between "then" and "now" and by so doing to demonstrate what a really valuable tool the genius of the present day has given us in the milling machine.

In order to afford anything like a review of this subject, it will be necessary to divide milling machines into certain main groups.

This, however, entails certain difficulties since the question as to whether to divide them according to their construction, according to the manner in which they perform their work, or according to the work which can be carried out on the machine, is one which it is not at all easy to answer, since many of the machines, although widely different in other respects, frequently have at least two of the foregoing factors in common.

Seeing that the construction and manner of working are the two factors most closely connected, we will, divide milling machines into three main groups, viz:

I. Horizontal milling machines.
II. Vertical milling machines.
III. Milling machines which are a combination of types I and II,

and thus, passing over the special types of milling machines, we can take the general types of each of the principal groups seriatim and afterwards treat of the special machines of each type separately.

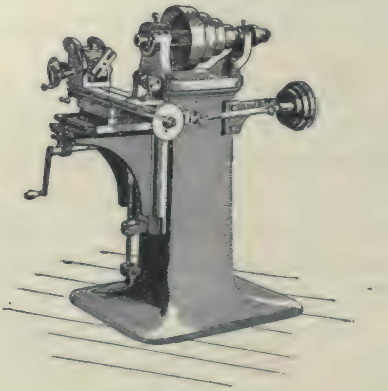


Fig. 196.
Universal milling machine of the year 1865.

Grouping the machines in the manner indicated above, the chief varieties can be subdivided as follows:

Column and knee type milling machines.
Slab „ „
Circular „ „
Thread cutting „
Gear „ „
Vertical milling „
Profile „ „
Two spindle „ „
Key seat „ „
Special „ „
Combined „ „

As regards the various forms, the column and knee milling machine, which is the fundamental type, has preserved its original form to a marked degree as is clearly shown in figs. 196 and 197, there being a difference of a good 40 years in the construction of the two machines. As regards the vertical milling machine, its form bears a strong resemblance to that of the slotting machine, whilst the slab miller greatly resembles the planing machine; the thread cutting machine is not unlike the machine it supercedes, viz: the lathe, whilst the newer types of milling machines, such as gear hobbing- and key seat milling machines, etc., have all more or less their own special forms.

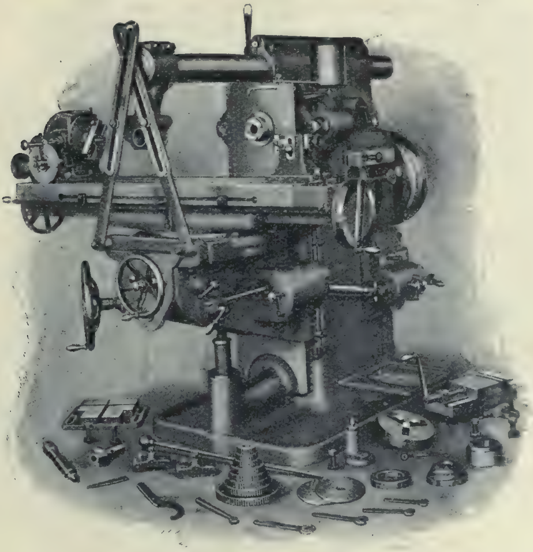


Fig. 197.
Universal milling machine of the year 1909.

The column and knee type milling machine.

Fig. 196, illustrates the universal milling machine first manufactured by the then firm of J. R. Brown, patent for which was granted on 21st February 1865, whilst the opposite illustration, fig. 197, depicts a universal milling machine of the very latest construction turned out by the present firm of Brown & Sharpe.

Notwithstanding the great difference in the construction of these two machines, the fundamental principles of the original constructor as well as the general appearance of the machine have been preserved up to this latest type. The machine has been improved upon and altered, but has still retained its characteristics.

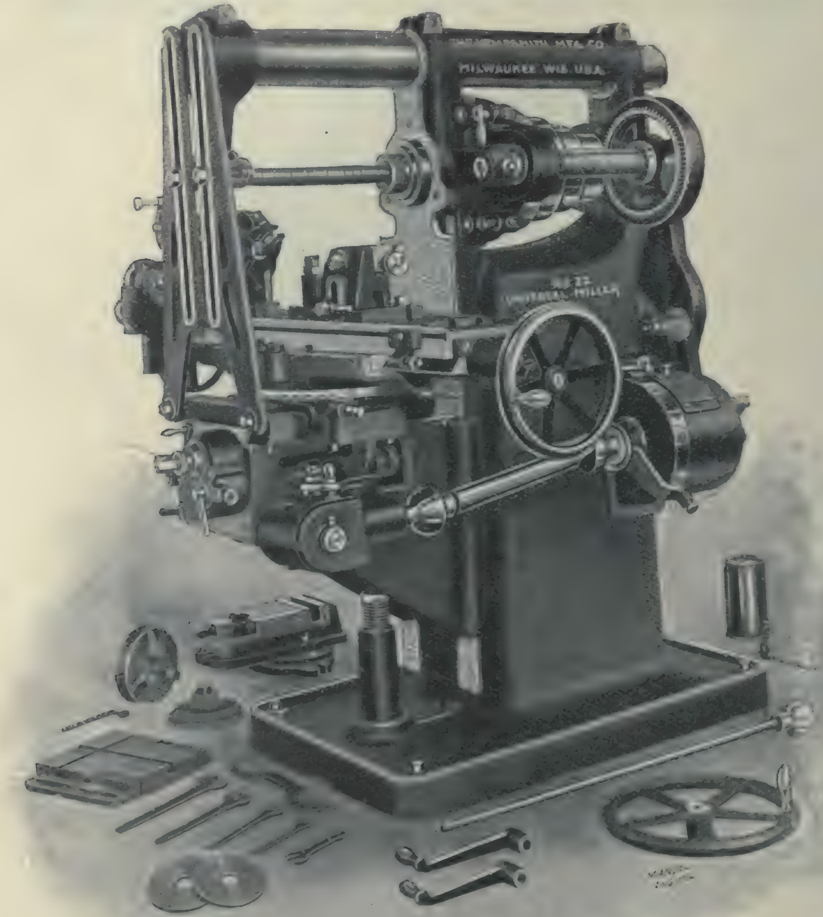


Fig. 198. Universal milling machine with cone drive.

(*a*). THE MAIN SPINDLE.

In the universal milling machine, a general illustration of which is given in fig. 198, the spindle, its housing and the method in which the spindle drive is effected are some of the principal points of its construction.

The main spindle has a hole through its entire length, the front end being provided with a conical bore to take arbors, cutters, drills etc. The spindle nose projecting beyond the housing is threaded to receive large cutters, or a universal chuck. The thread on the spindle nose is the same as the thread on the spindle of the universal dividing head so as to permit of the use of the same universal chuck. In order to prevent any possible injury, the thread is protected by a cap.

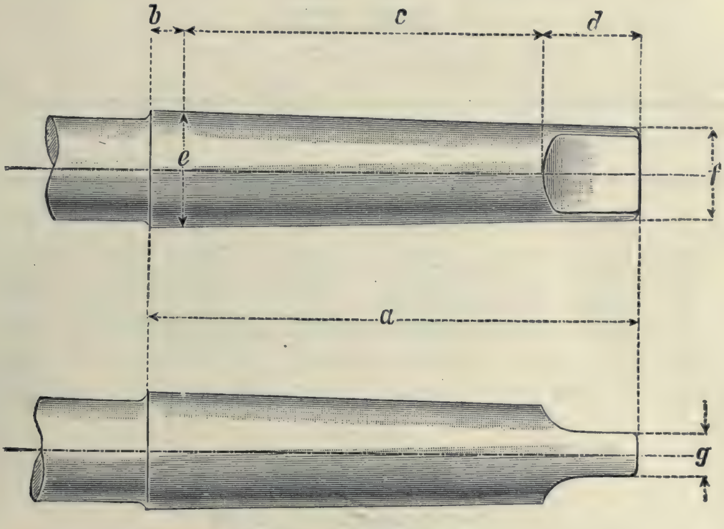


Fig. 199—200. Morse-taper.

The greater number of manufacturers have accepted for the conical bore the standard fixed upon by Brown and Sharpe for the taper. A few manufacturers on the continent, such as Loewe, have their own special standard tapers. The Morse-taper, which is in general use for twist drills, is seldom used for milling machines owing to its being too taper. The dimensions of the various tapers mostly used are given herewith.

As regards the dimensions of the Morse-taper, these are very divergent, there being no generally accepted dimensions. Reinecker, a German maker of milling machines, proposed in the "Verein Deutscher Maschinen-Ingenieure" to substitute for the Morse-taper a metric cone of the dimensions given in table XXII. However, nothing definite came of it.

Table XXI.

Morse-taper. N⁰. 1—6.

No. of taper.		*a*	*c* + *d*	*f*	*e*	*g*	Taper per foot.
1	Inches	$2^{9}/_{16}$	$2^{3}/_{8}$	.356	.475	$^{13}/_{64}$	.600
2	„	$3^{1}/_{16}$	$2^{7}/_{8}$	.556	.700	$^{1}/_{4}$	.602
3	„	$3^{3}/_{4}$	$3^{9}/_{16}$	.759	.938	$^{5}/_{16}$	.602
4	„	$4^{3}/_{4}$	$4^{1}/_{2}$	.997	1.231	$^{15}/_{32}$	.623
5	„	6	$5^{3}/_{4}$	1.446	1.748	$^{5}/_{8}$	.630
6	„	$6^{5}/_{6}$	8	2.077	2.494	$^{3}/_{4}$	.626

Table XXII.

Metric-taper. N⁰. 1—6.

No. of taper.		1	2	3	4	5	6
a	mM.	64	84	104	124	144	165
b	„	4	4	4	4	4	5
c	„	52	70	88	106	124	142
d	„	8	10	12	14	16	18
e	„	12	18	24	32	40	50
f	„	9	14	19	26	33	42
g	„	5	6.5	8	11	14	17
Degree of taper per 100 mM.		5					

Table XXIII.

Loewe-taper. N⁰. 3—12.

No. of taper.	3	3*a*	5	5*a*	6*b*	8	9	11	12
a mM.	88	94	127.5	117	122	171.5	173.5	217	259.5
b „	4	5	5	6	6	8	8	9	10
c „	70	77	105	93.5	94	136.5	140	178	216
d „	14	12	17.5	17.5	22	27	25.5	30	33.5
e „	10.63	14.27	19.81	18.49	23.25	32.84	31.65	41.63	50.8
f „	10.73	10.34	14.34	15.22	18.59	26.26	25.03	32.27	41.27
g „	5.6	5.1	7.6	7.6	9	12	12	14.5	15.5

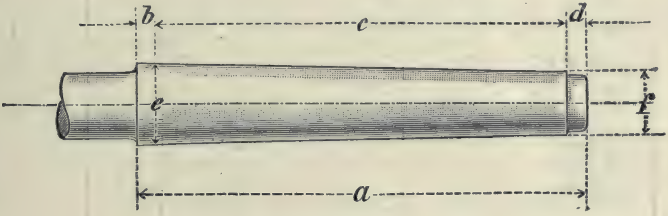


Fig. 201.
Loewe-taper.

Table XXIV.

Loewe-taper. letters *f*—*p* to fig. 201.

Cone letter.		*f*	*g*	*h*	*i*	*l*	*m*	*n*	*p*
a	mM.	99	115	135	152	186	201	218	251
b	„	5	5	5	6	8	8	9	11
c	„	90	105	125	140	170	185	200	230
d	„	4	5	5	6	8	8	9	10
e	„	20	24	28	31.5	39.9	44	48	60
f	„	15.5	18.75	21.75	25.088	32.08	34.75	38	48.5

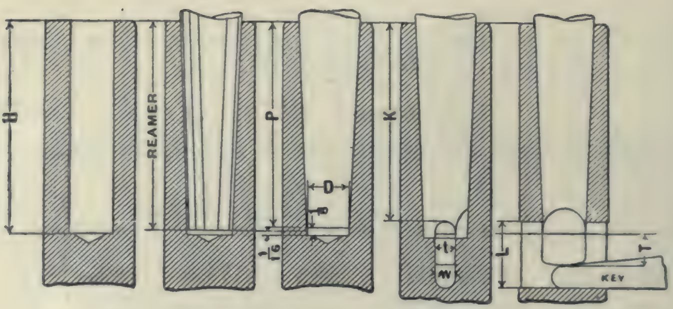


Fig. 202—206. B. and S. taper.

Table XXV.

Brown and Sharpe-tapers. N⁰. 1—18.

No. of taper.	D	P	H	K	L	W	T	*t*	tapered
1	.20	1/16	1 1/16	1 5/16	3/8	.135	3/16	1/8	.500
2	.25	1 3/16	1 5/16	1 11/64	1/2	.166	1/4	5/32	.500
3	.312	1 3/4	1 7/8	1 23/32	5/8	.197	3/16	3/16	.500
3	.312	2	2 1/8	1 31/32	5/8	.197	5/16	3/16	.500
4	.35	1 1/4	1 3/8	1 13/64	11/16	.228	11/32	7/32	.500
5	.45	1 3/4	1 7/8	1 11/16	3/4	.260	3/8	1/4	.500
6	.50	2 3/8	2 1/2	2 19/64	7/8	.291	7/16	9/32	.500
6	.50	3 1/4	3 3/8	3 11/64	7/8	.291	7/16	9/32	.500
7	.60	3	3 1/8	2 29/32	15/16	.322	15/32	5/16	.500
7	.60	4	4 1/8	3 29/32	15/16	.322	25/32	5/16	.500
8	.75	3 9/16	3 11/16	3 29/64	1	.353	1/2	11/32	.500
9	.90	4	4 1/8	3 7/8	1 1/8	.385	9/16	3/8	.500
10	1.0446	5	5 1/8	4 27/32	1 5/16	.447	21/32	7/16	.5161
10	1.0446	5 11/16	5 13/16	5 17/32	1 5/16	.447	21/32	7/16	.1561
10	1.0446	6 7/32	6 11/32	6 1/6	1 5/16	.447	21/32	7/16	.500
11	1.25	6 3/4	6 7/8	6 19/32	1 5/16	.447	21/32	7/16	.500
12	1.50	7 1/8	7 1/4	6 15/16	1 1/2	.510	3/4	1/2	.500
13	1.75	7 3/4	7 1/8	7 9/16	1 1/2	.510	3/4	1/2	.500
14	2.	8 1/4	8 3/8	8 1/32	1 11/16	.572	27/32	9/16	.500
15	2.25	8 3/4	8 7/8	8 17/32	1 11/16	.572	27/32	9/16	.500
16	2.50	9 1/4	9 3/8	9	1 7/8	.635	15/16	5/8	.500
17	2.75	9 3/4	9 7/8	—	—	—	—	—	.500
18	3.00	10 1/4	10 3/8	—	—	—	—	—	.500

The hole through the main spindle serves for drawing and pushing in and out the milling arbor which is fixed in the spindle. The simplest way of mounting is that in which the cutter or arbor is just placed in the conical bore without further fixing. Fig. 207 shows an end mill of this description.

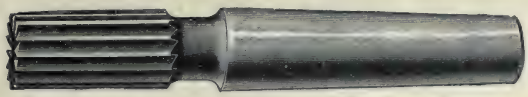


Fig. 207. End mill with taper shank.

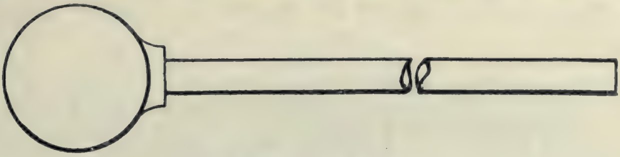


Fig. 208. Counterweight.

The cutter or arbor is thrust out by a rod, the end of which is provided with a ball for the purpose of adding weight to the rod. (Fig. 208). Other makers provide either the end of the cutter or of the arbor with an internal thread and the arbor is drawn in the conical bore by means of a bolt through the spindle. (Fig. 210).

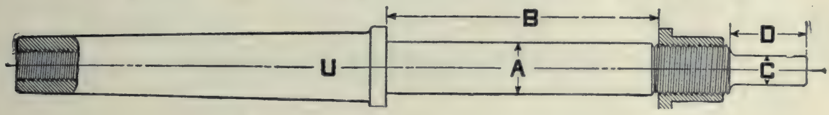


Fig. 209. Milling arbor with taper shank.

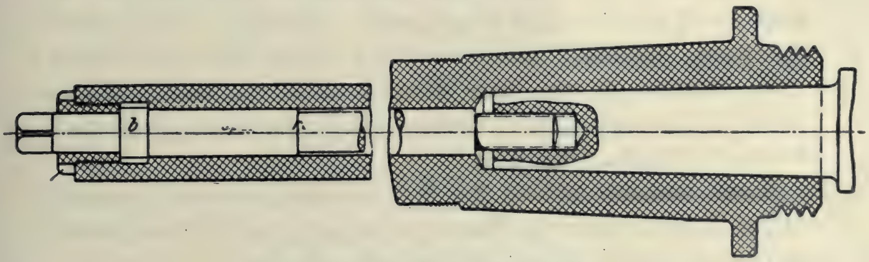


Fig. 210. Headstock main spindle.

It is clear that back thrust is no longer possible as this would injure the thread and render it useless. The same bolt which is used to draw the arbor in the bore, is, in a very simple manner, employed to push it out (fig. 210).

By means of a crank handle on the square the bolt *b* is screwed into the arbor. The rod is provided with a collar *b*.

If screwing the rod into the arbor, the collar will have its end thrust against the edge in the end of the main spindle and consequently draw the arbor into the conical bore and thus fit it tightly in the spindle. At the end of the spindle is a stop screwed in it. If now the bolt be turned in an opposite direction, the collar will thrust against the stop in question, thus forcing the cutter or arbor out of the bore. Another means of preventing the taper shank from rotating in the bore is to provide the cutter or the arbor with two flats, the spindle nose being recessed correspondingly. (Fig. 211).

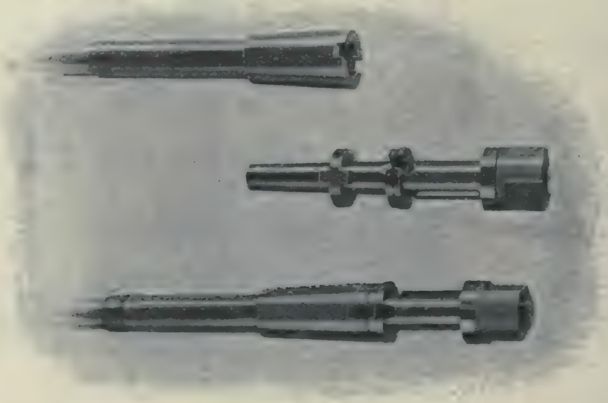


Fig. 211. Headstock main spindle and milling arbor.

Some makers employ the first-named device as illustrated in fig. 210 exclusively, but a combination of the two systems shown in figs. 210 and 211 is also met with.

As another means to ensure the cutter or the arbor having a tight fit in the bore, the difference in pitch between two threads, the so-called "differential thread" is made use of.

This manner of fixing is much in use on milling machines the spindle of which has no hole. A differential nut, (fig. 213), fits on the threaded front end of the spindle which is, for example, $^1/_7$ inch pitch.

The nut, however, has still a smaller bore provided with a finer thread, for instance, 11 threads per inch, the same thread being also on the cutter. Each turn of the nut causes it to travel forward $^1/_7$ inch on the spindle, but only $^1/_{11}$ inch on the cutter, the cutter thus being driven into the bore the difference between $^1/_7$ inch — $^1/_{11}$ inch = $^4/_{77}$ inch per turn. Care must be taken when screwing up the nut not to drive the cutter fast into the bore at once, as otherwise, the cutter will be firmly secured directly the nut has travelled over one or two threads, which is unsufficient.

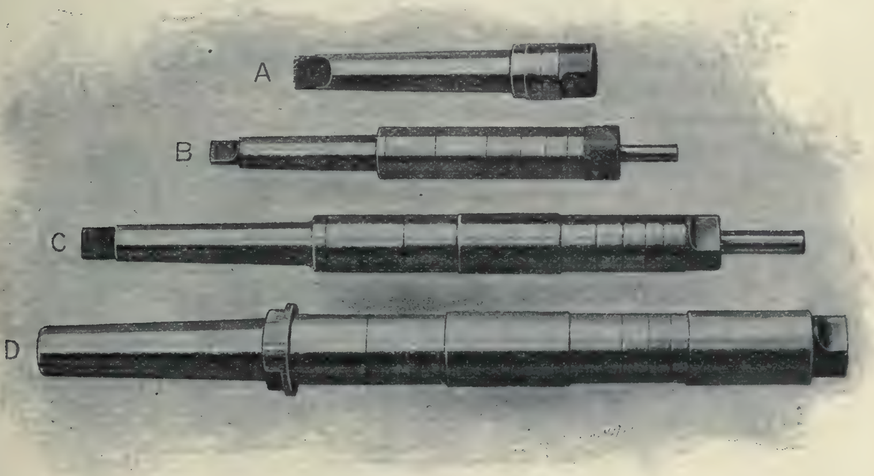


Fig. 212. Milling arbors of different forms.

To remove the cutter, all that is necessary is to turn the nut back which releases the cutter from the bore.

The differential screw is based upon the same principle. (Fig. 214). The end of the screw fits in the cutter, or arbor which, for instance, is provided with a $^3/_4$ inch thread with 10 threads per inch. At the other end of the rod and at the rear of the hole in the spindle is a finer thread, for instance, 12 threads per inch. The cutter is now thrust into the bore by the difference of $^1/_{10}$ inch — $^1/_{12}$ inch = $^1/_{60}$ inch at each turn of the rod as just described above. As the differential thread is absolutely reliable, there is no fear of this means of fixing working loose.

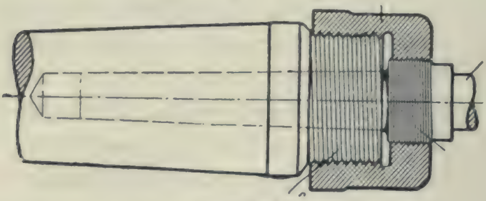


Fig. 213.
Fixing the milling arbor with differential nut.

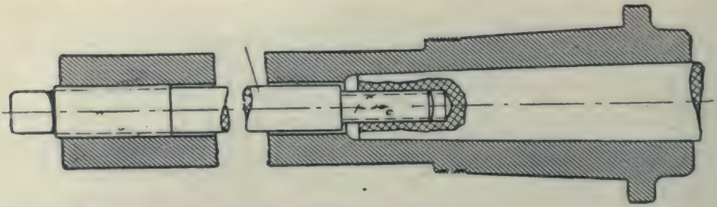


Fig. 214. Fixing the milling arbor with differential screw.

(*b*) THE HOUSING OF THE MAIN SPINDLE.

The spindle is carried in bronze, babbit or cast iron bearings. In order to ensure accurate work, it is a matter of primary importance that the spindle should fit its bearings perfectly.

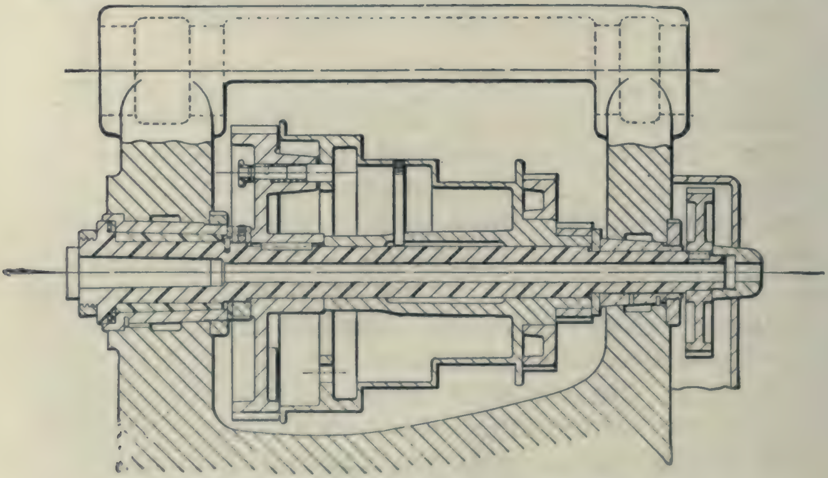


Fig. 215. Sectional view of Le Blond headstock.

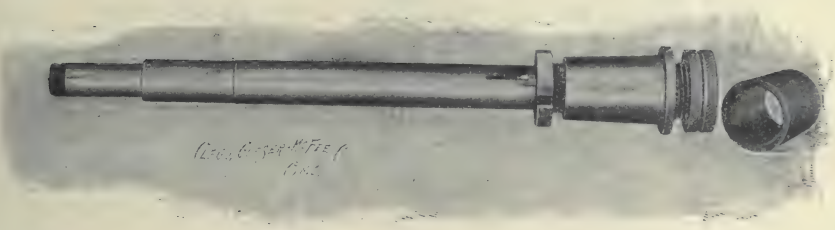


Fig. 216. Le Blond main spindle.

The form of the headstock with the bridge for the overhanging arm on top prevents the use of bearings in halves. It is, nevertheless, imperative that the spindle can be housed in the bearings with perfect accuracy whilst, at the same time, re-adjustment for wear must also be possible. The front journal is almost universally conical, the rear one being cylindrical, whilst the method of re-adjustment is very divergent.

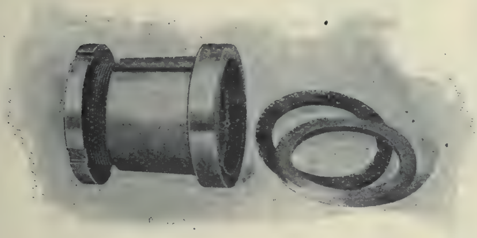


Fig. 217. Le Blond front box.

Fig. 215 gives a sectional view of the headstock of the Le Blond milling machine. Fig. 216, shows the spindle separately, figs. 217 and 218 the front and rear boxes. The front journal is conical and hardened. For this reason, the journal consist of a hardened steel bush pressed on the spindle. (See figs. 215 and 216). The front journal runs in a cast iron box. (Fig. 217).

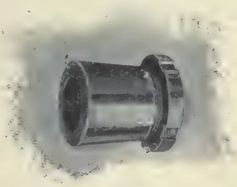


Fig. 218.
Le Blond rear box.

The two surfaces which thus come in contact with one another and run one on the other are hardened steel and cast iron. As wear or roughening by a very hard spindle is impossible by efficient lubrication, the internal surface of

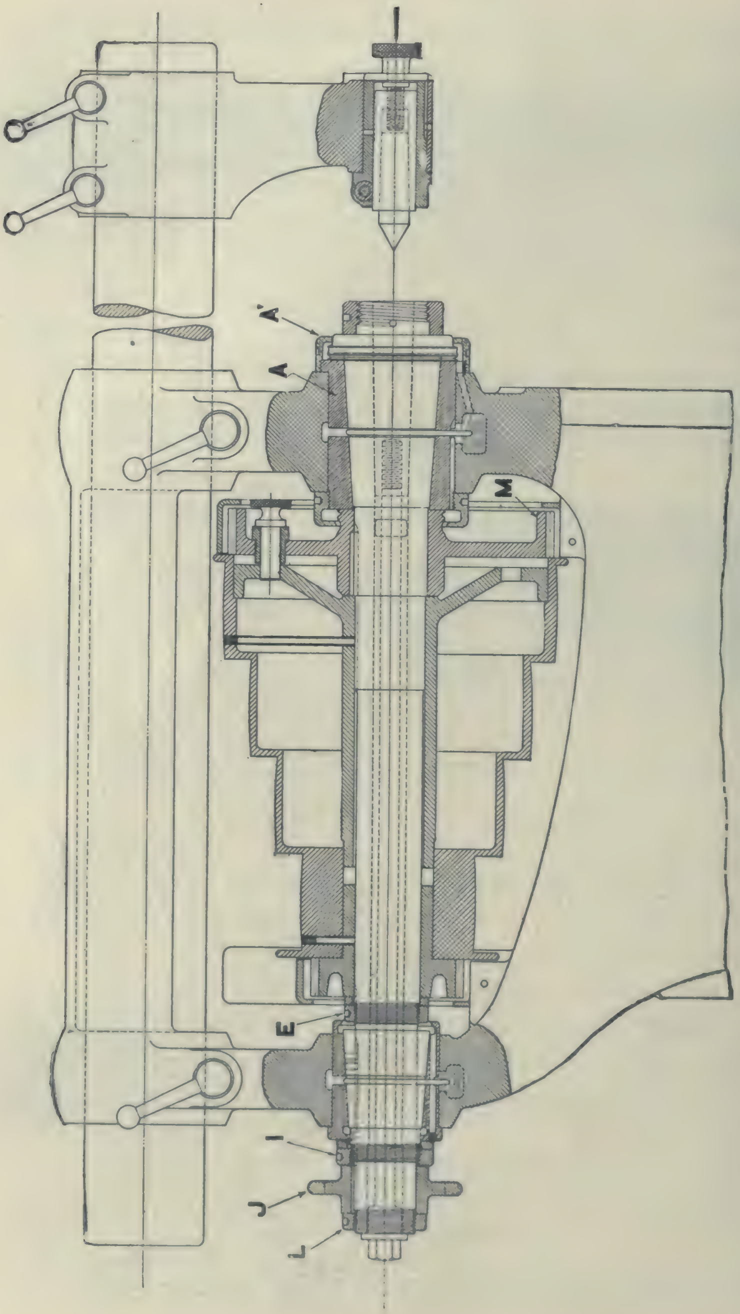


Fig. 219. Sectional view of universal milling machine.

the cast iron box will quickly become perfectly smooth so that the ultimate wear will be almost imperceptible. The rear journal of the spindle is cylindrical and carried in a box with cylindrical bore and tapered on the outside. (Fig. 218). This box is split, and can be drawn in the column to take up the wear centrally. The end thrust is taken up by one hardened steel and one babbit collar. (Fig. 217). An oil slot is milled in both boxes which is filled with felt which absorbes and filters the superfluous oil, thus providing efficient lubrication for the spindle in its bearings.

In some makes the adjustment is effected by the spindle and the front box not being adjustable whilst in other constructions on the other hand, the wear is taken up by the adjustable split box. The first named is the principle adopted in the construction shown in fig. 215.

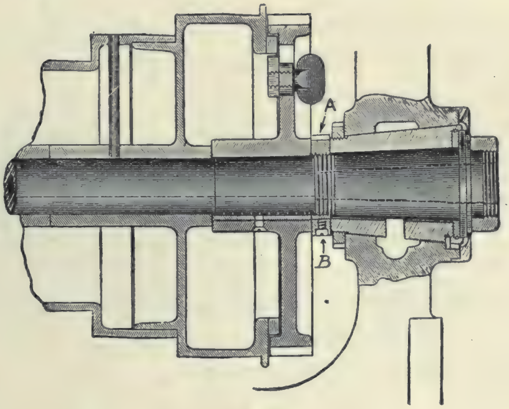


Fig. 220.
Sectional view main spindle.

To adjust the spindle in the front bearing, the nut at the rear of the front journal, is tightened, whilst for the rear bearing the nut on the box is tightened. The nut on the spindle, (fig. 216), draws it towards its taper bearing, enlarging the space between it and the gear wheel and taking the end thrust against the box. The nut on the rear box draws it into the column compressing it on the journal.

Fig. 219 shows a totally different construction. Both bearings are conical. The spindle is adjustable for the front bearing, the box for the rear bearing. Both journals of the spindle are tapered in the same direction. The front box A, is fixed in the column by the nut B on the inside. The cap A′ serves to protect the bearing from dust and dirt.

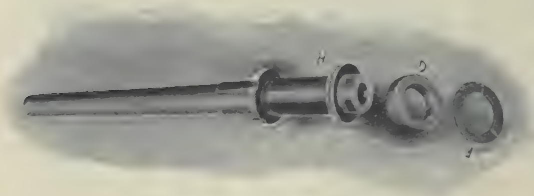


Fig. 221.
Headstock main spindle of fig. 220.

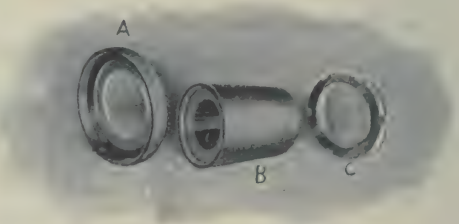


Fig. 222.
Front box of main spindle of fig. 220.

The spindle is enclosed in the front bearing in a transverse direction. On the front, the raised edge of the spindle thrust against the front of the box, on the back-side, the hub of the gear wheel M thrust against the box A. The nut at the back of the box also acts as a dust cap. Should it be desired to adjust the spindle in the front bearing, the nut E should be tightened which will cause the spindle to be drawn toward the conical bore, since the cone pulley with the gear wheel M is placed between this nut and the front box. The rear box, and this is the principal point in this form of construction, is thus entirely independent of the spindle and can be adjusted by turning the nutcollar I forward or backward, which causes the box to be moved forward toward the tapered journal of the spindle. Both bearings have ring oiling, an oil-pocket being provided for each in the column.

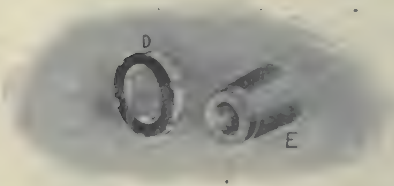


Fig. 223.
Rear box of main spindle of fig. 220.

In fig. 220 the front box is tapered inside as well as outside. In order to adjust the spindle, the screw B which by means of a brass shoe locks the nut A firmly against the thread of the spindle is loosened. After being loosened, the nut A can be tightened, drawing the spindle in the conical bore. This spindle is also self-oiling by means of felt. The construction of the rear box is as shown in fig. 215. Fig. 221 illustrates the spindle. The nose is threaded to receive a chuck. F is a hardened steel washer behind collar H on spindle; the threaded dust-cap is placed behind the edge H of the spindle. The front box B is illustrated in fig. 222.

This solid bronze box is tapered in and outside and tightened by nut C. A is the dust-cap of the bearing.

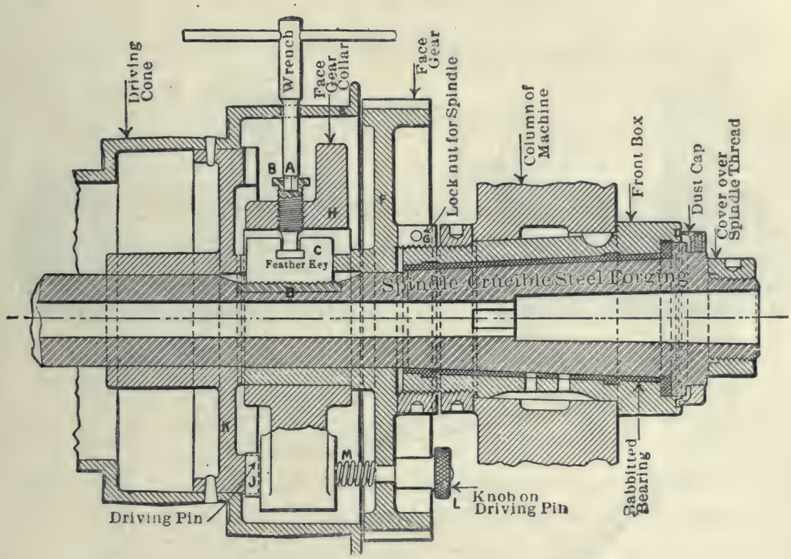


Fig. 224. Sectional view main spindle Cincinnati milling machine.

Fig. 223 illustrates the rear box.

Figure 224 shows another construction of the main spindle. In this case the spindle is carried in a conical babbit lined box. The spindle is provided at D with a notched keyway; the face gear F is mounted on the spindle, together with the ring H which is attached thereto, by means of the notched feather-key C which meshes the notches of the keyway. In order to adjust the spindle, the nut G is turned against the face gear F. This locknut is placed on the extended portion of the front box and serves to thrust the face gear backward and with it the spindle in the conical bore. If the spindle has been repeatedly adjusted, it is possible that the space between the front box and the face gear has become too great. In order to remedy this, the lock screw B with feather key C is loosened by means of the wrench A; the locknut G is turned back to its original position; the cone pulley and face gear can be drawn forward by hand against the nut G, after which the spindle can be again properly adjusted in the bearing, by means of the nut G, the feather key C being first properly fixed. The exceptional length of the front bearing should be specially noted. The rear box is of the split type, tapered externally with a cylindrical bore; the spindle oiling with felt.

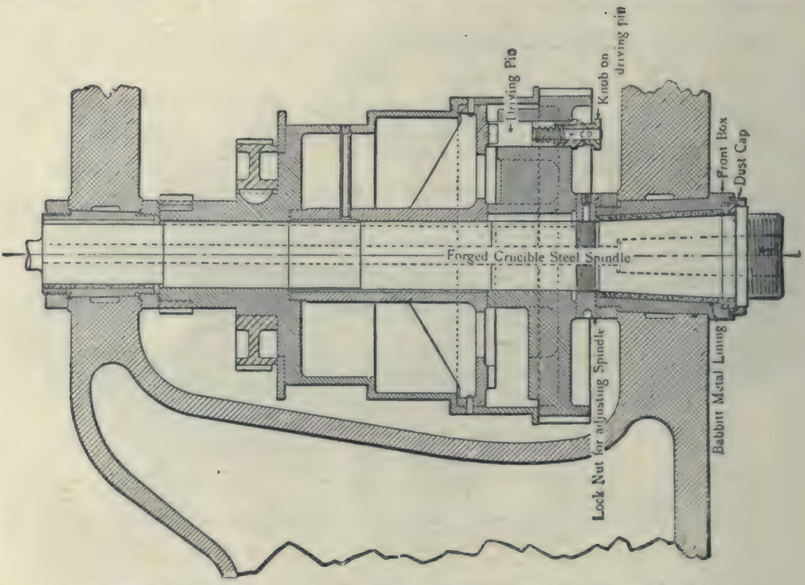


Fig. 225. Sectional view main spindle Cincinnati milling machine.

This construction of the Cincinnate millers, was employed up to 1904, when it was discontinued, its place being taken by the construction shown in fig. 225. The in and outside tapered babbited spindle box at front have remained, as also the construction of the rear box, but the manner of adjustment of the front bearing has been changed and now

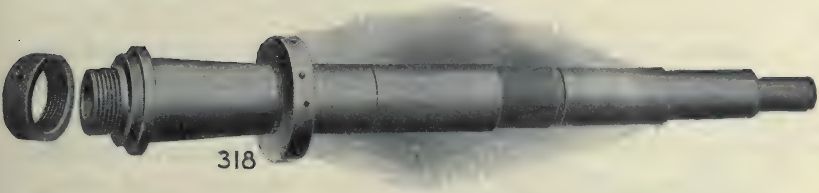


Fig. 226.
Main spindle Cincinnati milling machine.

corresponds more closely with the constructions which have already been described.

The spindle is threaded behind the front journal (figs.

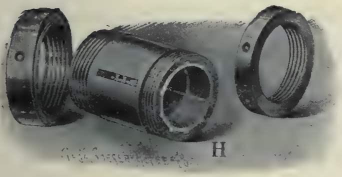


Fig. 227.
Rear box Cincinnati milling machine.

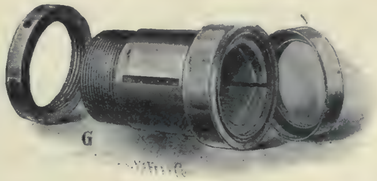


Fig. 228.
Front box Cincinnati milling machine.

225 and 226), and a lock nut is tightened against the rear end of the front box, thus drawing the spindle in the bearing.

A totally different construction of the front box is shown in fig. 229. The spindle is carried in a solid, bronze box with conical bore. The edge of the spindle is covered by a cap attached to the column by adjustable screws; on both sides of the edge is a hardened steel washer, whilst between the box and the steel washer next to it, that is the surface which has to take up the thrust and is consequently liable to wear, is a babbitt ring.

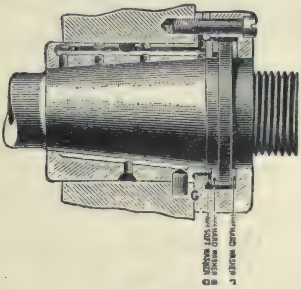


Fig. 229.
Front box Garvin milling machine.

c. THE DRIVE.

Owing to the fact that only light work was carried out on the milling machine on account of the then undeveloped state of the science of milling, the milling machine was formerly only direct driven by the cone pulley on the spindle and, consequently, the number of speeds which could be obtained was limited by the number of steps on the cone pulley. (fig. 230). When, however, at a later period, work of a heavier character was performed on the milling machine, it was provided with back gear, (fig. 231), by means of which, with a certain number of revolutions of the cutter, the speed of the cone pulley was from 8 to 9 times faster, the belt thus being able to transmit considerably more power.

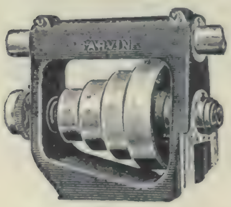


Fig. 230.
Plain cone drive.

With the increased use of high speed steel and the greater demands as regards capacity which were made upon the milling machine, the power of the belt proved a serious obstacle. To surmount this difficulty, two things were possible, viz:—(1) to increase the width of the belt, (2) to raise the ratio speed of the belt to that of the cutter, in other words, to increase the driving belt speed. In either case, however, fresh difficulties were encountered.

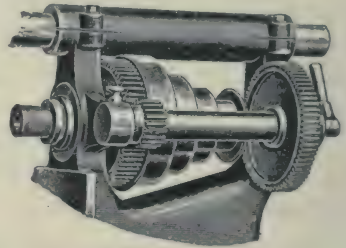


Fig. 231.
Cone drive with back gear.

1st. If the width of the belt were increased, this would have to be done at the expense of the number of steps on the cone, i. e. the number of speed variations, and this could not be dispensed with, 2nd. If the ratio of back gear were increased, an exact geometric ratio of speed was impossible. By combining the two, the advantages of both were obtained with none of the disadvantages. The number of steps of the cone pulley was reduced from 4 or 5 to 3, whilst double back gear, (fig. 232), was introduced, the first with a smaller, the second with a greater ratio, for instance 3. 6 : 1 and 13. 1 : 1. The result was a considerable increase in the width of belt and an increased belt speed whilst a correct geometric ratio was also rendered possible. Moreover, a double friction countershaft took the place of the ordinary fast and loose pulleys which had previously been employed, so that the countershaft could run at two speeds and in this manner with only a three-step cone pulley 2 × 3 × 3 = 18 spindle speeds were obtained. It goes without saying that this kind of gearing is only applied to the heavier types.

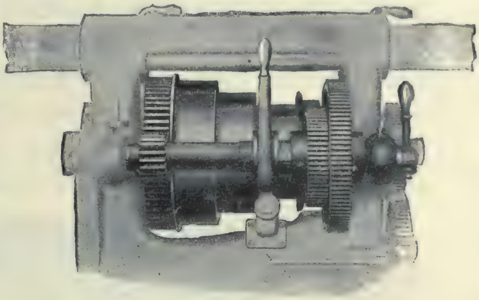


Fig. 232.
Cone drive with double back gear.

An additional improvement was also introduced, in that the connection between the spindle and the cone pulley was no longer obtained by means of a pin M, (see fig. 224), but by a friction actuated by a lever placed in front of the machine.

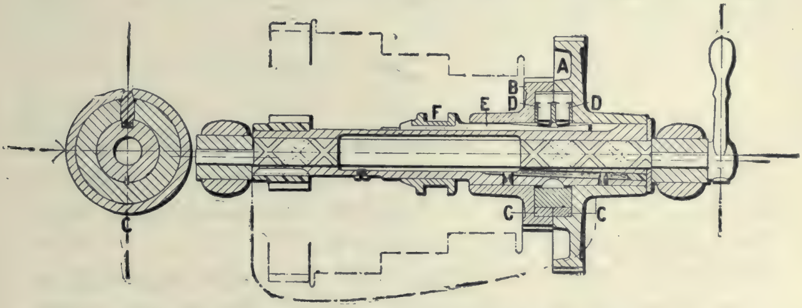


Fig. 233. Sectional view of double back gear shaft.

The back gear, figs. 232 and 234, can be disengaged eccentrically by the lever on the right hand side. (figs. 233 and 234). It consists of a double set of gear wheels, two wheels of different diameter are fixed to the cone pulley, and two wheels, also of different diameter, are carried by the back-gear shaft. Both these wheels are disengaged whenever the lever in fig. 232 is in the vertical position. This lever moves the sleeve F, (fig. 233), with key E. The two gear wheels A and B are recessed whilst *each* of them has a *separate* friction ring C. The friction rings are split and in the opening is a key D which, on being moved upwards, opens the ring C and engages it either with the wheel A or with the wheel B.

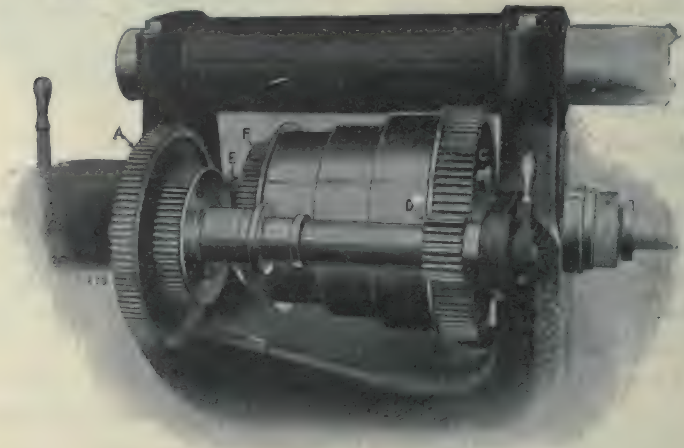


Fig. 234. Cone drive with double gearing in front.

The keys DD rest on the key E which is sloped to either side. If the friction lever be drawn to the left, the right hand key is raised, the large wheel A being engaged; if the lever be drawn to the right, the left-hand key is raised, the small wheel B being thrown in.

The most recent improvement in this construction is shown in fig. 234 which shows the double gear no longer at the *back* of the machine, but at the *front* and consequently in easier reach of the operator.

Although this construction cannot yet be said to belong to past history, it is still decidedly out of date, or, should this definition be deemed too strong, it has been replaced by entirely new and modern constructions.

Of late years the milling machine has made rapid progress, so rapid in fact, that certain manufacturers have simply passed over the newer constructions described above and now arrange the spindle drive as illustrated in fig. 235.

With the cone pulley drive, the belt cannot be stretched as tightly on the pulley as one could wish. It must always be possible for the operator to shift the belt from one step to the other. Moreover, the width of the belt is rather limited. In the machine illustrated in fig. 235, the cone pulley has disappeared entirely and the drive is effected by one pulley without the necessity of changing the belt. The number of spindle speeds is obtained by a set of gear wheels enclosed in the column. Fig. 236 shows those gears with the cover removed and thus makes their position quite clear.

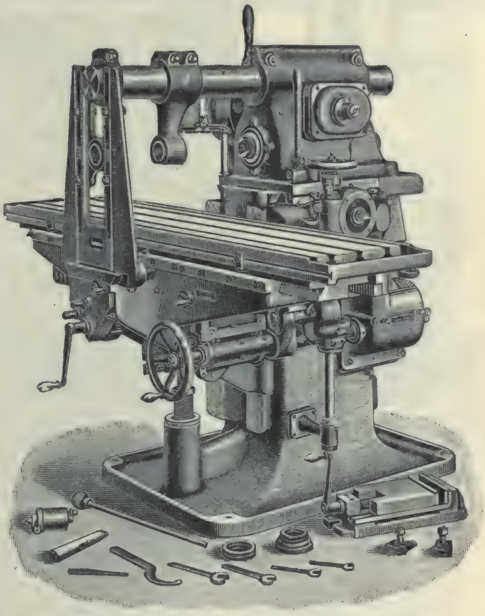


Fig. 235. Single pulley drive.

A pulley of large diameter and of such width as is considered desirable is mounted on a shaft at the back of the machine. On this shaft, which runs inside the column, is placed a gear wheel which can be meshed with any one of the six gears of the cone by means of a handle. In this manner six spindle speeds can be obtained and, seeing that the machine is also provided with double back gear, eighteen spindle speeds can be obtained from one speed of the driving pulley. The upper handle on the column in fig. 237 either engages or disengages the spindle for direct drive or drive by means of back gear, whilst the lower handle gears up for either first or second back gear. By means of a hand wheel placed at the back of the machine, the spindle can be turned by hand either to mesh the gear wheels or to turn the spindle

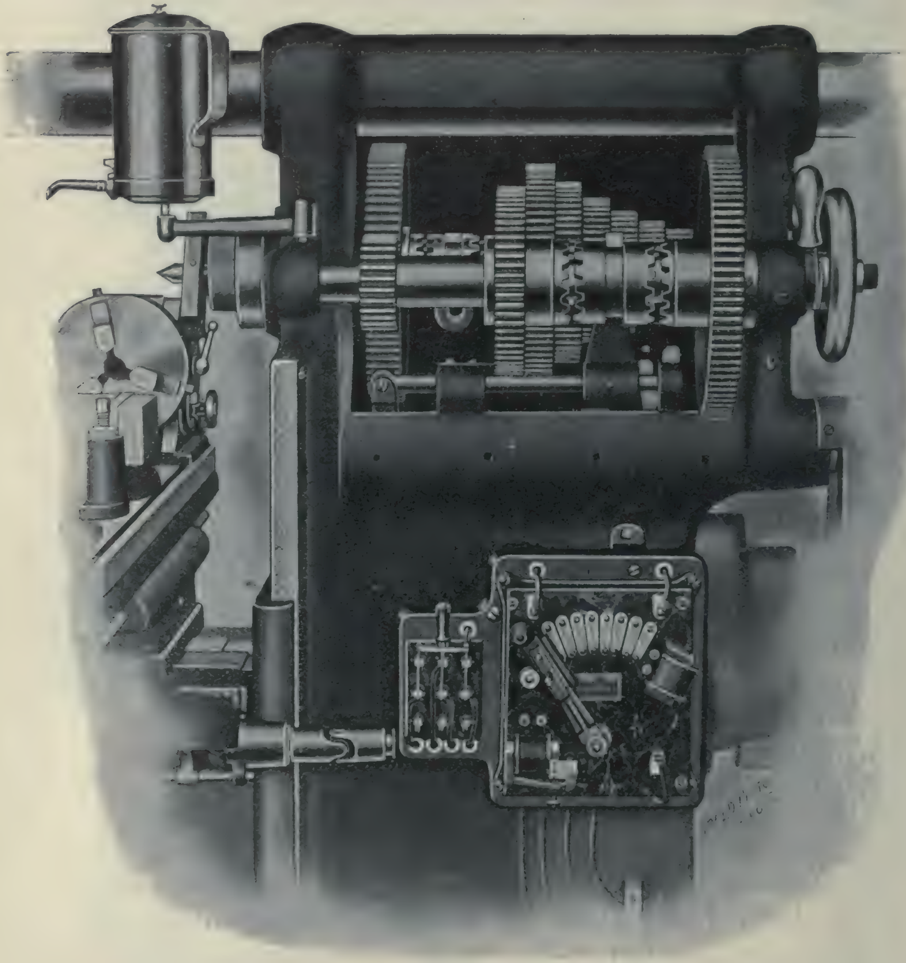


Fig. 236. Gear mechanism of single pulley drive.

as desired for the adjustment of the cutter. This construction is eminently adapted for direct electromotor drive. (Fig. 237).

A fuller description of this single pulley drive mechanism is given on pages 232 to 250.

(*d*). FEEDS.

In the case of the column and knee type machine the cutter rotates in a fixed position whilst the workpiece, which is fixed on the table, is fed along the cutter. This movement must be vertical and in the horizontal plane in transverse and longitudinal direction to the main spindle. It must, therefore, be possible to impart three different motions to the workpiece, whilst by making the table swivel in the horizontal plane, every angle varying from transverse to longitudinal to the main spindle, is obtainable by setting the table at a certain angle to the main spindle.

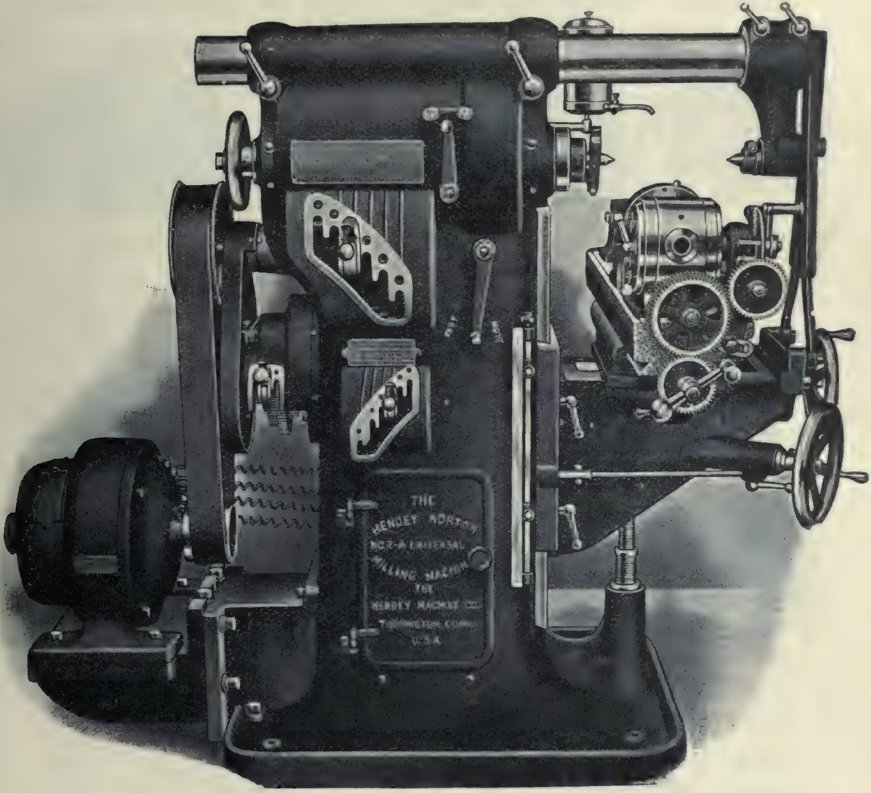
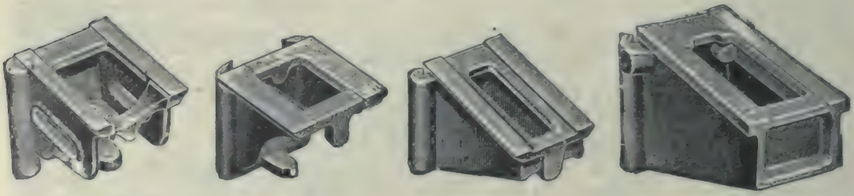
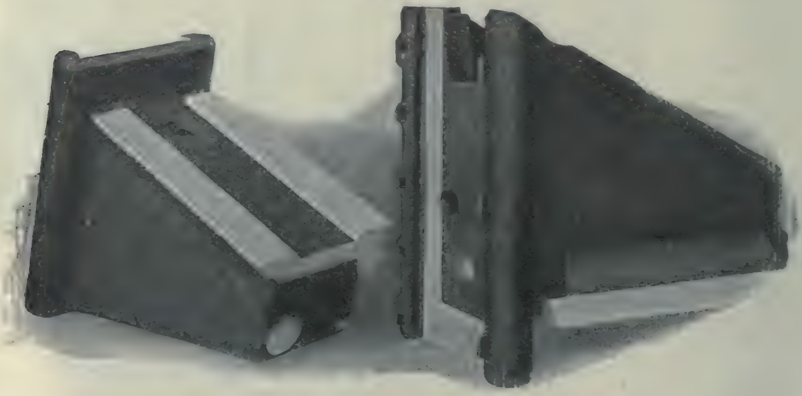


Fig. 237. Single pulley drive machine direct driven by electromotor.

The construction of the feed mechanism is of just as much importance as the construction of the main spindle and its drive and forms together with the latter and the universal dividing head, the principal parts of the horizontal milling machine.

Originally the column, (see fig. 196), was a box-formed casting, with flanged base so as to obtain sufficient stiffness. On the front side is a planed surface to which a knee is attached. On top this knee is planed and on this the saddle bearing the table fits with a taper gib whilst on top of the saddle, square on the knee, it affords guidance to the table. The saddle of the universal milling machine consists of two parts which swivel in a horizontal plane one on the other and by turning the table and upper part of the saddle the table can be shifted from the square and set at any angle.


Type 1862. **Type 1881.** **Type 1897.** **Type 1899.**
Fig. 238—241.


Type 1908.
Fig. 242. Different forms of knee.

If the workpiece be moved vertically, then all the abovementioned parts will be moved; if it be moved parallel to the main spindle the position of the knee remains unchanged, the saddle moving with the table; if which is frequently the case, the workpiece be moved square to the main spindle or at an angle to it, then only the table is moved. It is evident that in order to obtain a rigid smooth cut, the knee must be of ample strength to resist the strain exercised on the workpiece and also that the connection to the column, which is only of a temporary nature, must be so as to make it practically one piece.

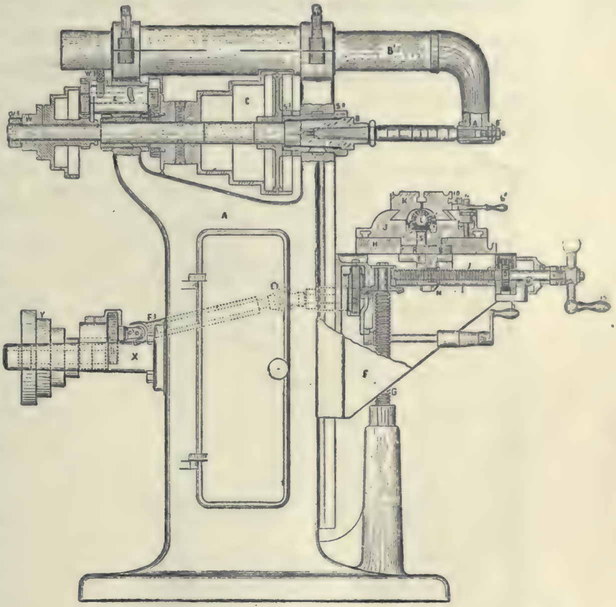


Fig. 243. Sectional view of headstock and knee.

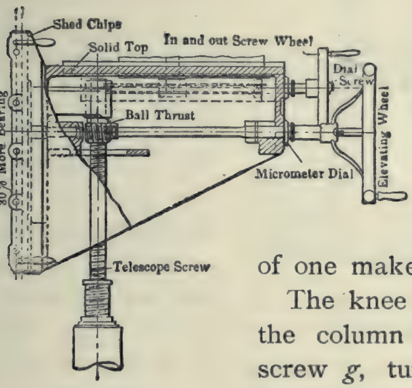


Fig. 244.
Knee section.

In proportion as the work to be performed on the milling machine is heavier, the knee must be more rigid. Figs. 238—242 illustrate five different forms of knee showing the constructions of one maker from 1862 to 1908.

The knee is moved vertically along the column by means of a telescopic screw *g*, turning in a bearing of the knee, (fig. 243), and which runs in a long nut fastened in an extension on the base. Originally the screw spindle was fastened on the knee, a thread being cut in a handwheel bearing in the extension piece on the base, so that when the handwheel was turned, the screw *g* and with it the knee was moved up and down. It was then necessary to have a hole under the base to receive the screw when the knee was at its lowest position. The workman was then obliged to bend down on the base in moving the knee and thus lost sight of the work. For this reason the handwheel was replaced by a nut fastened in the extension piece on the base, the spindle being moved by means of a handwheel mounted on a spindle which imparted motion to the screw *g* by means of two bevel gears or a worm and wormwheel (fig. 244). This handwheel is placed on the knee in easy reach of the operator so that he can devote his attention to the work. The sectional drawing, (fig. 243), shows one of the bevel gears, the handwheel, which is at one side, not being visible.

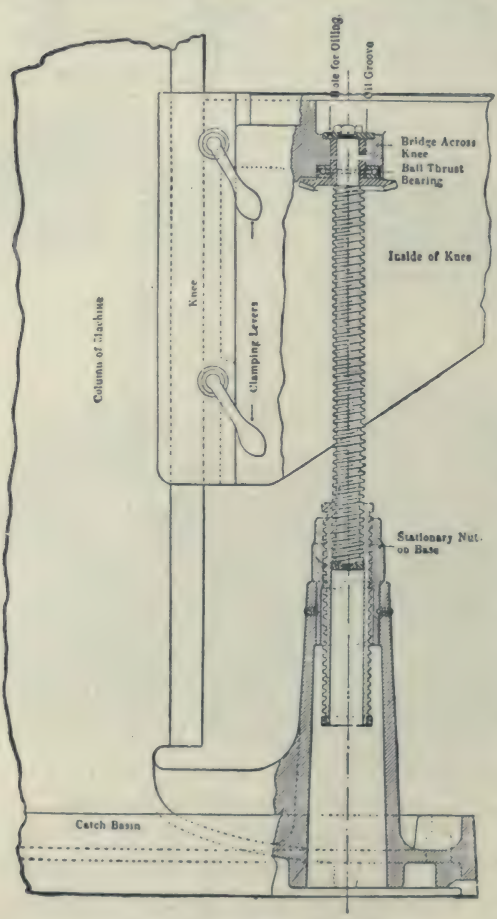


Fig. 245.
Sectional view of telescopic screw.

Fig. 244 shows how the movement from the handwheel to the screw by means of worm and wormwheel is transmitted. This illustration also shows the telescopic screw, a sectional drawing of which is given in fig. 245. This construction does away with the necessity of making a hole in the ground under the base.

The bevel gear on the vertical feed screw which has to take up the pressure of the knee, is provided with a ball thrust bearing so as to ensure the least possible friction.

Fig. 246, shows one of the latest constructions of the Garvin Machine Co. In this case the screw is once again made fast, being fastened *not* to the knee but to the base; the nut attached to the knee is moved by a hand-wheel and bevel gears which move the knee vertically. A ball thrust bearing is placed just were the knee bears on the nut.

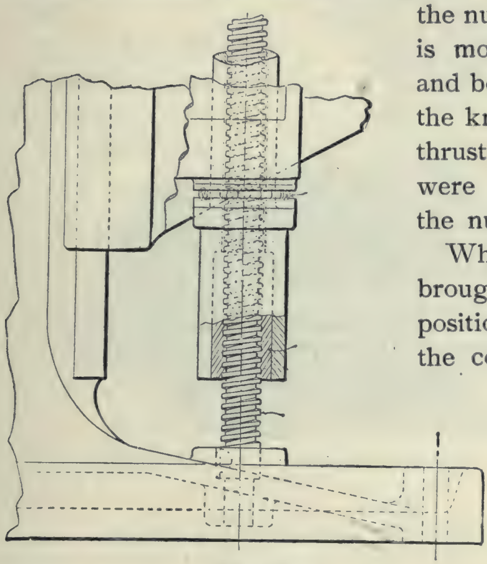


Fig. 246.
Telescopic screw.

When the knee has been brought to the requisite position, it is connected to the column by means of a steel taper gib, fastened by clamping bolts or levers, which fills up the space between the guides of the knee and those of the column. Fig. 247 illustrates a very simple and efficient clamping device. By giving the clamping levers half a turn, the knee is firmly secured to the column.

The dimensions of plain and universal milling machines have been considerably increased of late years, the weight of the workpieces which are handled on the machine and which the knee consequently has to bear being also increased. The greater part of the weight has to be borne by the telescopic screw, for which reason this has latterly been made much heavier and more rigid.

In order to give the knee sufficient strength to resist collapsing strains and to efford proper support to the work-piece, some makers have of late built a knee support on the base which is bolted to the knee, thus obtaining a box form, the upper surface of which is formed by the top of the knee. (fig. 248). Any danger of an undue top weight and consequent bending of the knee or variation from the dead level is thus effectually prevented.

This construction has not facilitated the handling of the machine, though in certain cases where the work is exceptionally heavy, it may be necessary.

Originally the table was made to be moved automatically

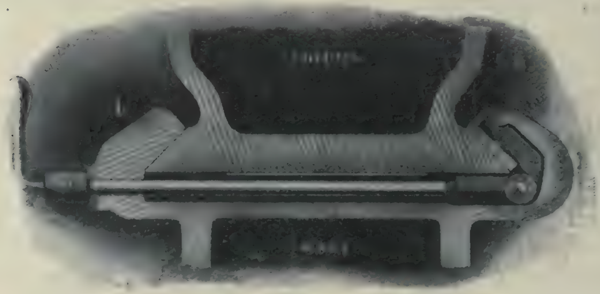


Fig. 247.
Clamping device of knee.

square to the main spindle. Fig. 249 shows one of the first constructions of feed mechanism. The cone pulley 1, which is driven by a belt from a counter pulley mounted on the main spindle, drives the telescopic shaft H, which is provided on either side with a universal joint and which can follow the table motion in a vertical direction. It drives the worm, which meshes the worm-wheel 3 mounted on the table feed screw T which moves the table. Should it be desired to move the table automatically in an opposite direction, the belt driving the cone pulley 1 is crossed.

Between this construction and what nowadays is demanded and realized in this respect, lies a great distance which the milling machine has rapidly traversed in the course of but a few years. The milling machine of to-day is provided with:

1. Automatic vertical feed in either direction.

2. Automatic longitudinal table feed in both directions.

3. Automatic cross feed in both directions.

4. The reversal of all feeds takes place independently of the drive, which continues uninterruptedly in one direction.

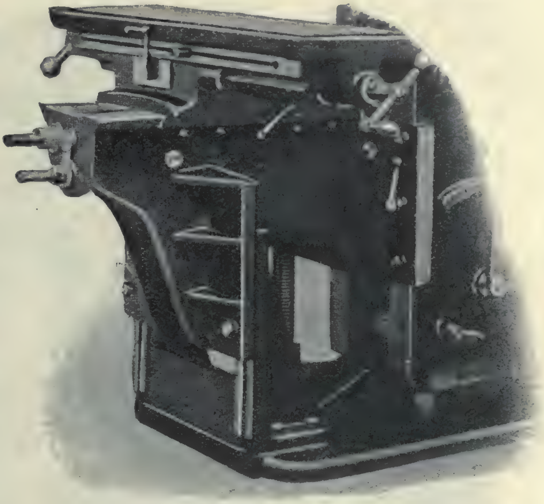


Fig. 248. Knee support.

5. All feeds are driven from a common shaft.

6. All feeds can be automatically disengaged in either direction.

7. The feed drive is positive, in other words, without belts, whilst there is a fixed ratio between the spindle speeds and the feed shaft by means of gearing.

8. The number of feed changes with the same spindle

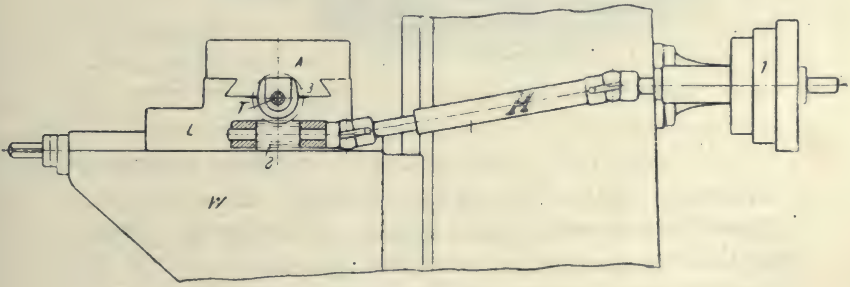


Fig. 249. Plain table feed.

speed, originally three, has been increased to 12 or 20, all of which are reversible whilst the machine is running by a simple movement of a lever.

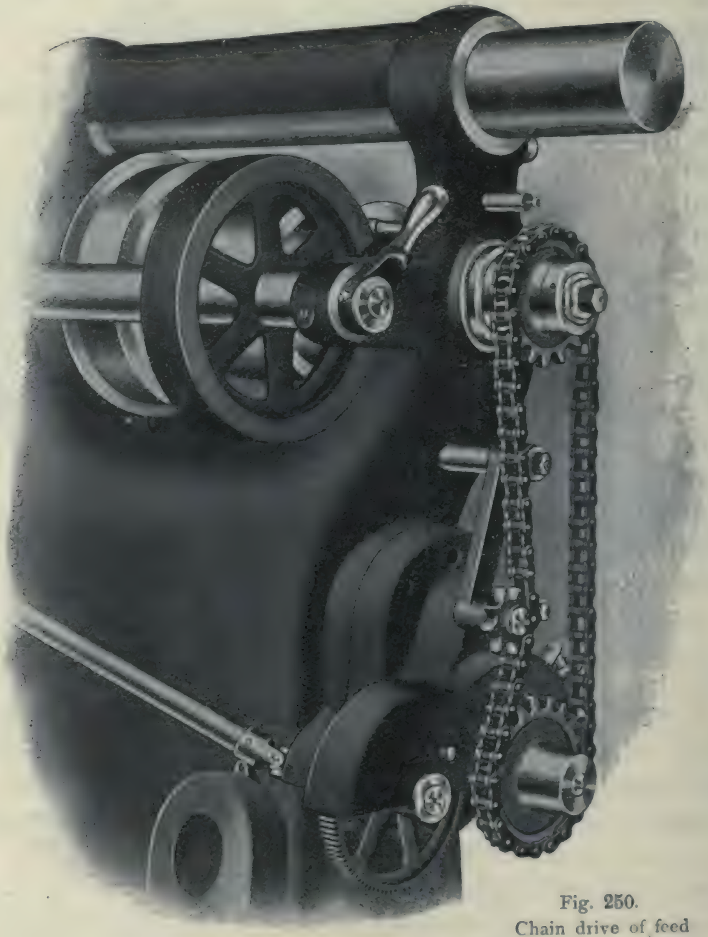


Fig. 250.
Chain drive of feed mechanism.

9. All feeds can be manipulated from where the operator is standing, i. e. in front of the machine.

By some makers the feed shaft is driven by gear wheels, by others by means of a chain and sprocket wheel (fig. 250), by others again by means of a shaft driven by bevel gears, (fig. 251); in each case, however, there is a fixed ratio between the speed of both shafts.

A gear box is placed between the feed shaft and that which further transmits the movement and by shifting levers, different gear wheels can be meshed in, each of which causes a different ratio between the driving gear and the one driven, and by this the shaft behind the gear box is caused to rotate either faster or slower, the feed being dependent on the speed of the last named shaft.

Certain manufacturers, as, for instance, the Kempsmith Mfg. Co. (figs. 252 and 253), and Brown & Sharpe, (fig. 254), unite all these changes of speed in one box; others, on the contrary, such as the Cincinnati Milling Co. divide them over two boxes, (figs. 251 and 255).

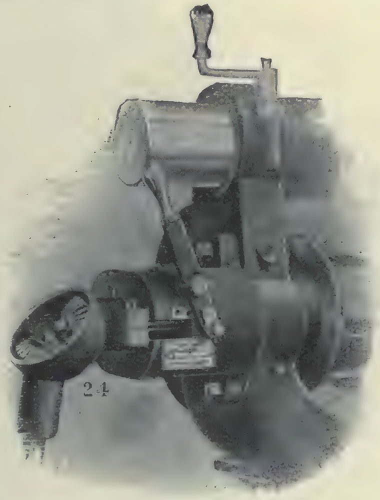


Fig. 251. Upper feed drive of the Cincinnati milling machine.

The gear box of the Kempsmith milling machine is provided with an index plate, which is clearly visible in the illustration, (fig. 252). The feed changes are effected by means of three levers, one on either side of the box, and one on the top. The lever on the top is turned either to the right or to the left, i. e. to H or G. The lever on the left-hand side can be set in four positions viz:—A. B. C. and D.

The lever to the right can be placed in three positions; the middle one to disengage the feed, the upper and lower, E and F, for meshing different gears; by this means $2 \times 4 \times 2 = 16$ different rates of feed are obtained for each spindle speed varying from 0.004″ to 0.15″ feed per revolution of the spindle.

With the upper lever, (fig. 252), turned to G, and the right-hand lever in E, 0.004, 0.005, 0.006 and 0.008″ feeds are obtainable when the left-hand lever is moved from A to D. If the right-hand lever be brought over to F, 0.01, 0.013, 0.017 and 0.022″ feeds are obtained by shifting the left-hand lever again from A to D. If the upper lever be brought over to H and the righthand lever again placed in E, then 0.027, 0.037, 0.047 and 0.06″ feeds are obtained consecutively with the left-hand lever and 0.074, 0.094, 0.118 and 0.15″ feeds consecutively with the right-hand lever in F.

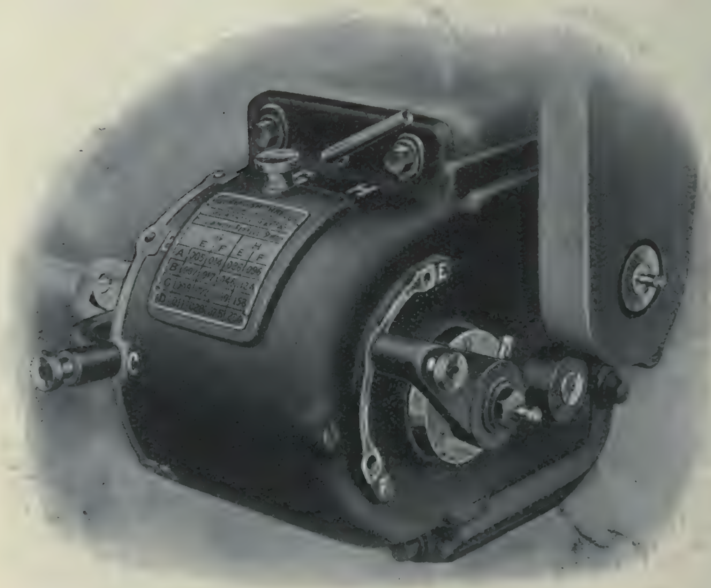


Fig. 252. Kempsmith feed gear box.

In the larger size machines the difference between the finest and coarsest feeds is somewhat greater, varying

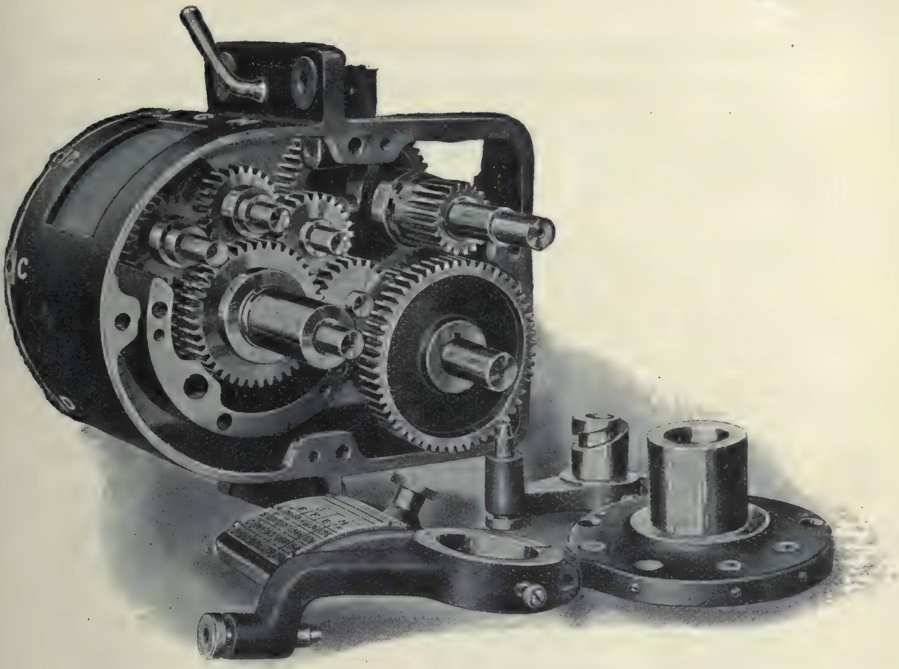


Fig. 253. Open feed gear box of Kempsmith milling machine.

from 0.005″ to 0.175″ per revolution of the spindle.

Fig. 253 shows the open feed gear box of the Kempsmith milling machine whereas fig. 256 gives a sectional view in which all

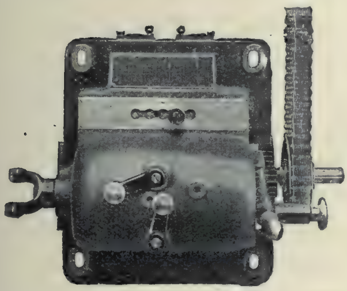


Fig. 254.
Brown and Sharpe feed gear box.

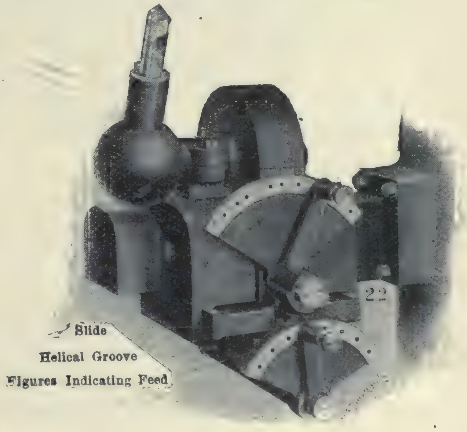


Fig. 255. Lower feed drive with feed gear box of the Cincinnati milling machine.

the gears are shown *as if* they were lying in one plane, which, however *is not* actually the case. A is the sprocket wheel driven from the spindle and mounted on the shaft B so that its speed is always in relative ratio to that of the main spindle. A double clutch C engages by means of D either on the left-hand side the gear wheel E or on the right-hand side the pinion F so that two speeds are imparted to the shaft G viz:—a slow speed by F and a faster speed by E. In addition to the corresponding wheels on E and F, a set of 4 gear wheels of different diameters are mounted on the shaft G. Another set of wheels corresponding with the wheels on shaft G run idle on the shaft H which transmits the motion. The wheels on the shaft H are enclosed in a swinging cage I actuated by the lever L and driven by two intermediate gears, one of which, K, is to be seen in fig. 256. Together with the lever L these intermediate wheels bring in mesh the gears on the shafts G and H. A gear wheel M mounted on a stud in the shear N, drives the pinion O; P and Q are clutches, keyed to the shaft H. A sleeve R, has a helical groove which is operated by lever S (see fig. 253) to engage either P or Q. If Q be

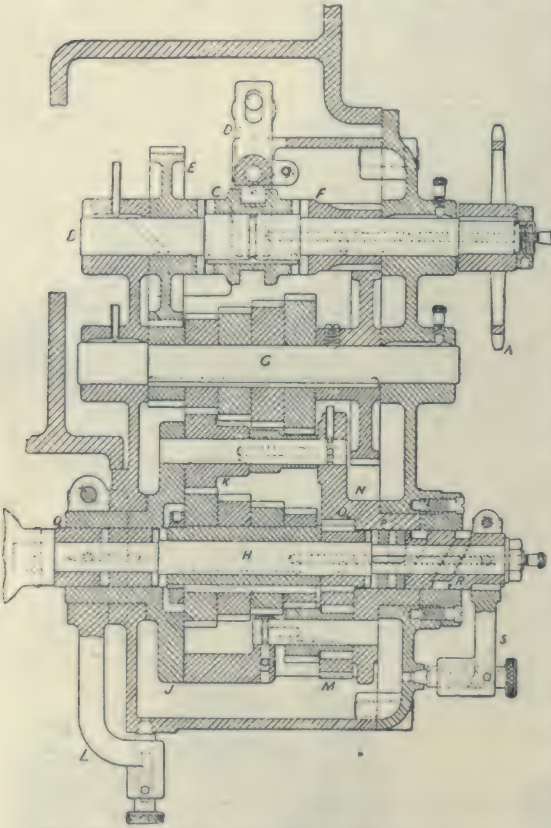


Fig. 256. Sectional view Kempsmith feed gear box.

engaged, the wheels on the shaft H drive the shaft direct, if P be engaged, by means of the transmission M and O.

The smaller sizes of the Cincinnati milling machines have 12 changes of feeds, the larger sizes 16, varying in the case of the smaller machines from 0.04″ to 0.2″ per revolution of the spindle, and for the larger from 0.006″ to 0.3″. The feed mechanism consists of two parts, (figs. 251 and 255); fig. 257 gives a sectional view of the mechanism shown in fig. 251, whilst fig. 258 shows the gear box of fig. 255 open. The upper gear box, (figs. 251 and 257), imparts two speeds to the vertical shaft which transmits the motion to the lower gear box. By means of a lever to be seen in fig. 251, the vertical feed shaft speed can be increased from the large to the small wheel or slackened from the small to the large wheel fig. 257.

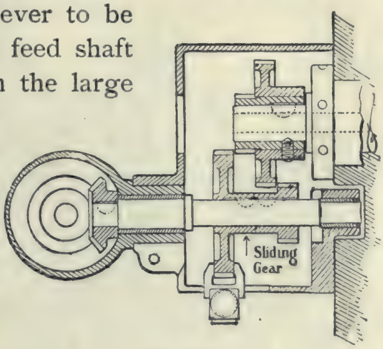


Fig. 257.
Sectional view upper feed drive Cincinnati milling machine.

The vertical shaft shown in fig. 255, to which 2 speeds can thus be imparted, drives by a set of bevel gears a horizontal shaft on which two gears of different diameter are keyed, which in their turn drive two sets of cone gears, each consisting of 4, all of which run idle on the same shaft, each set independent of the other. The *large* upper wheel meshes the *smallest* wheel of the one set, the *small* upper wheel meshing the *largest* wheel of the other set, so that these two sets of cone gears run with a great difference in speed. From the 8 gear wheels of these two sets which run together in pairs though each with a different speed, motion is further transmitted through an intermediate gear sliding on its shaft along a keyway by means of a rack and sector and placed into different positions to mesh each of the 8 gear wheels. This is the lower lever in fig. 255. Of the 8 wheels lying to the rear, the intermediate gear would, however, only be able to mesh with two of the gear wheels if the position remained unchanged. However, to enable the front wheel to mesh with the other gears, the upper lever, shown in fig. 255, moves on its hub by means of a helical groove when the lever is moved, the whole of the under part of the mechanism, sector, rack, wheel and shaft being also moved.

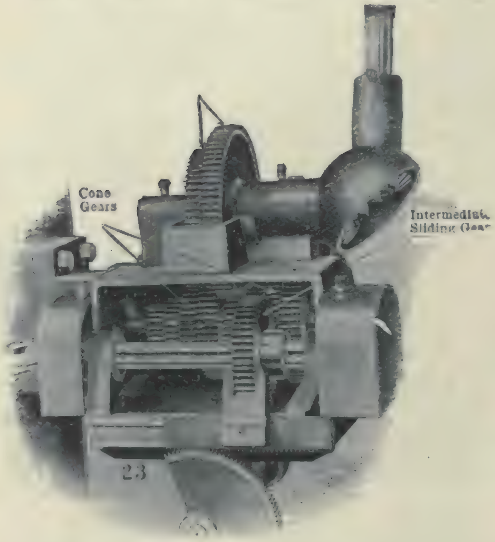


Fig. 258.
Open feed gear box of Cincinnati milling machine.

The precise manner in which the drive of the feed mechanism should be brought about is a question on which diverse opinions have been expressed by specialists as well as by the leading makers. It is generally agreed that the method which has so far been adopted is far from being the ideal, being dependent on the spindle speeds. The spindle speeds are chiefly fixed by the diameter of the cutter, whilst it goes without saying that the rate of feed has nothing whatever to do with the question as to whether a cutter has a diameter of $^{8}/_{4}$″ or of 8″, and yet for certain classes of work a cutter of the former diameter can be used equally as well as one of the latter. The plan has been considered of driving the feed mechanism independently of the speed of the main spindle direct from the countershaft, but this has one great objection, viz:—that should anything go wrong with the main drive of the machine, such as the breaking of the driving belt or something of the sort, the feed mechanism would continue running with the result that both machine and workpiece would run the risk of being ruined. The type of milling machine now built by Brown and Sharpe, Kearney and Trecker and the Cincinnati Milling Machine Co. with single pulley drive goes very far towards the solution of this question. The gear box as per fig. 254, is driven by B. and S. from the pulley spindle of the machine by means of chain and sprocket wheel; seeing that in the case of single pulley drive, this spindle rotates at an invariable speed, the feed can be determined per minute independent of the number of revolutions of the cutter. With the N^0. 2 A machine of Brown & Sharpe, the feed can vary from $^{1}/_{2}$″—6″, with the N^0. 3 A from $^{5}/_{8}$″ to 20″ per minute, which for small cutters gives a feed varying from 0.0016″ to 0.053″ and from 0.0017″ to 0.054″, and for large size cutters from 0.041″ to 1.333″ and from 0.039″ to 1.25″ per revolution of the cutter.

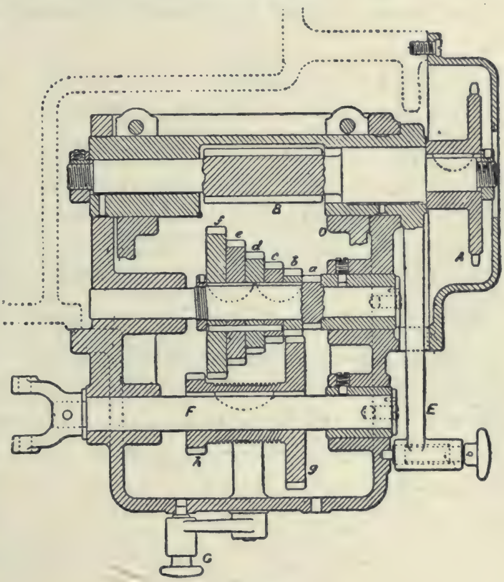


Fig. 259.
Sectional view B. and S. feed gear box.

Fig. 259 gives a sectional view of the mechanism of the Brown and Sharpe gear box illustrated in fig. 254. The sprocket wheel A drives the long faced pinion B. An idle wheel, not indicated, but mounted on a stud in the swing plate D, engages with either of the gears *a*, *b*, *c*, *d*, *e* or *f* by the lever E at the right hand side of the gear box, which lever can be set in a fixed position by means of a plunger which fits in a hole at the side of the gear box. In fig. 259, the wheel *b* is in mesh with *g* on the feed shaft F, but by giving the lever G a half turn to the right, *g* is slid out, and *h* put into engagement with *f*.

Fig. 260 shows the feed mechanism of the Garvin machines. The greater part of the mechanism is enclosed in the column, the lever K being on the outside. With this mechanism 18 different feeds are obtainable.

The sprocket wheel A is driven from the main spindle. By means of a sliding clutch, this wheel engages with the spur gear B, which is in mesh with the gear C, which is keyed to a short shaft on which three gears, D, are mounted; these three gears are in mesh with three corresponding gears, E, which run idle on their shaft and can each be coupled to their shaft by means of a sliding spring key, to be seen on the shaft itself. This shaft also carries to the right side another cone of three gears, F, keyed fast upon it, which communicate the motion derived from either one of the gears E. to three others G. idle on a short shaft; this shaft has no connection with that on which the wheels D are keyed; the motion of the gears G is then transmitted to the feed shaft by the mitre wheels H. For any one position of the sliding key in the wheels E there are three changes available by the key engaging with the

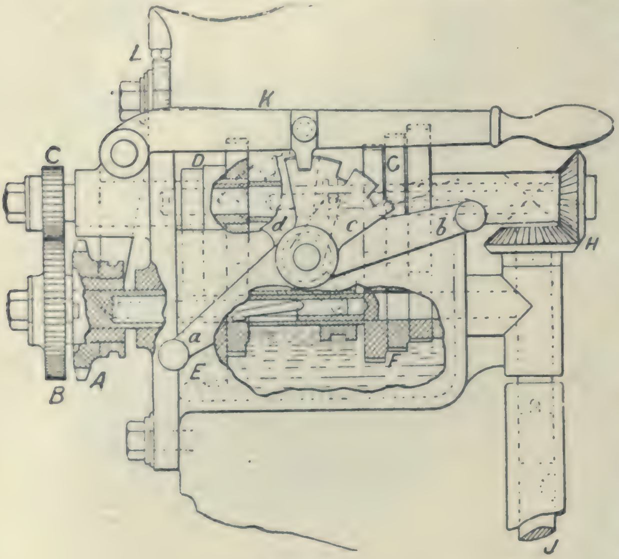


Fig. 260.
Garvin feed gear box.

wheels G, so that $3 \times 3 = 9$ speeds of H are possible. And besides, as the gears B and C are reversible, the series of nine changes can be doubled, thus making a total of 18 speeds possible, varying from $^1/_{270}$″ to $^1/_4$″ per revolution of the main spindle. Each sliding key is provided with a lever *a* and *b*, having notched sectors *c* and *d*, each of which is locked by the locking lever K. This lever when lifted, disengages at the same time sprocket wheel A from gear B, so that by changing the feed, the gears are stopped though the machine continues running.

All positieve feed mechanisms are provided with index plates indicating the different positions of the levers, stating the rates of feed which these will give, whilst there is also one position which disengages the feed shaft.

Starting from the feed shaft, the motion is imparted to three different points, viz:—for the vertical travel of the knee, and the longitudinal and cross travel of the table. Figs. 261—262 show the construction of the automatic travel of the Hendey milling machines.

All feeds are instantly started, stopped and reversed by the lever A, (fig. 261). When A is thrown to the right standing in front of the machine, all feed screw handles turn right handed and the table moves to the right, toward the column, and up. The handle D, (figs. 262), throws in the longitudinal movement of the table, the handle B, (fig. 261), the cross movement and the handle C, the vertical movement. Each feed has its own mechanism independant of the other feeds; consequently all may be engaged simultaneously or separately.

The machine is provided with 4 hand wheels for operating the various movements by hand. The cross movement of the table is effected by the hand wheel in front of the knee, the vertical movement being obtained by the hand wheel at the left hand side, whilst there are also two handles at either end of the table. The handle on the left hand side is connected directly to the feed screw spindle; each revolution of the handle causes the table to move over a length equal to the pitch of the feed screw.

On the right hand side is a handle, illustrated in fig. 262, for the quick movement of the table.

In the position shown in fig. 262, the handle is set for the quick return of the table. The handle is connected to the right hand gear and runs loose with this gear over its

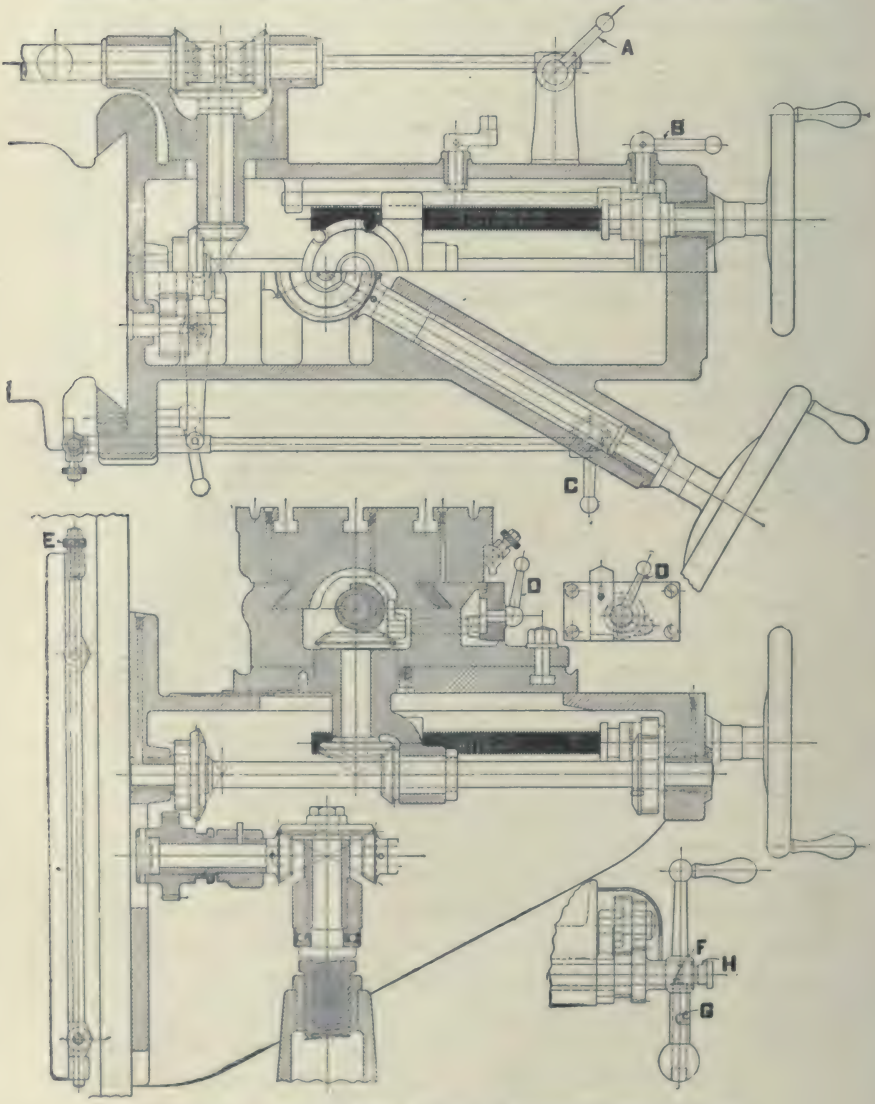


Fig. 261—262. Sectional views of knee of Hendey milling machine.

stud, imparting motion to the upper compound gear, the left hand gear of which meshes the gear beneath it, which, in its turn, is mounted on the feed screw.

From the feed shaft fig. 261, a third mitre gear is set in motion by two other mitre gears; this gear is mounted on a shaft which, in its turn, drives another set of mitre gears, the hub of the last gear being a spur gear. This gear meshes another gear which runs idle on a sleeve on the shaft lying underneath, (see fig. 262), which is provided with a clutch; by means of the lever to the left, this gear wheel is coupled to the shaft and, at the same time, engages the spur gears. As can easily be seen from fig. 262, this shaft drives the vertical telescopic screw. As will be seen from the illustration the automatic longitudinal and cross feeds are obtained by the large mitre wheel mounted on the shaft parallel under the cross feed screw (fig. 262). For the cross feed, a spur gear is mounted on the end of this shaft, which meshes a pinion that runs idle on the cross feed screw, but which by means of the lever B, (fig. 261), can be connected with a clutch on the cross feed screw. For the longitudinal feed of the table, the movement is transmitted to the feed screw of the table by three mitre gears. The further gearing is not visible in fig. 262.

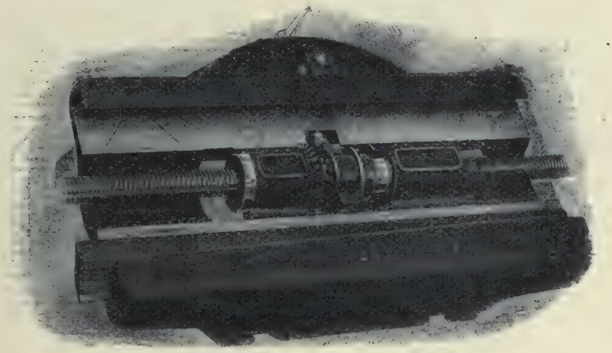


Fig. 263. Automatic longitudinal movement mechanism of milling table.

Fig. 263, however, shows the underside of the table of the Leblond milling machine, which, as far as this part is concerned, is similar to the Hendey machine. The upper mitre wheel on the vertical shaft in fig. 262, meshes the mitre wheel to be seen underneath the table, which, mounted on a sleeve, rotates free over the feed screw of the table. On the spindle is a clutch which, on being coupled with the mitre wheel by means of the lever D, fig. 262 causes the spindle to rotate by means of a key in the cluth and by this the table is moved. All automatic feed movements are thus engaged by clutches, being disengaged by trip dogs.

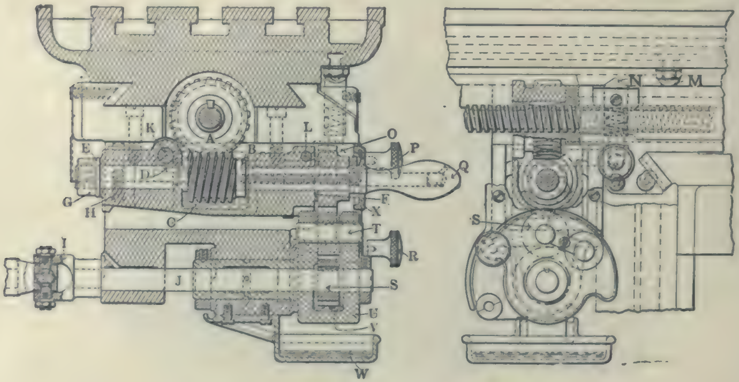


Fig. 264—265. Garvin feed mechanism.

The trips for disengaging the vertical automatic feed can be seen to the left in fig. 262, and can be properly adjusted by means of the knurled screw E.

Figs. 264 and 265 show the automatic feeds of the Garvin milling machine. I is a universal joint, receiving power from the feed shaft, which drives the driving shaft J of the feed movements. On this shaft is mounted the reversing tumbler gear S, which meshes the gear S to be seen in fig. 265, and also another small gear wheel. Both these gear wheels run idle on studs carried in the rocker casting U. This casting serves at the same time as an oil bath, so that the gears S run continuously in oil. The movement from the shaft J is transmitted to the gear wheel

O by means of the gears S. In fig. 264 the gearing takes place with one idle wheel; by reversing the knob R, the casting U is also moved and a second idle wheel is engaged, (fig. 265), by means of which the movement is reversed. The gear wheel O drives the worm shaft D with the worm C which meshes the worm wheel A mounted on the table feed screw. The shaft D is carried in a casting provided with an oil bath, in which the worm C runs. This casting can be dropped on the latch pin K and can be fixed in the position given in the illustration by which worm and worm wheel are in mesh by means of the pivot pin L. The table feed is disengaged by hand by means of the trip knob P. This can however, take place automatically by means of the trip button M, which acts on the hardened steel trip plug N, which is kept in the position shown in the illustration by a spring, but is pressed down by M, thus allowing the pivot pin L to fall, with the result that the worm C drops out of the worm wheel. In order to again engage, the handle Q, which is attached to the casting in which the worm shaft is carried, is pulled up.

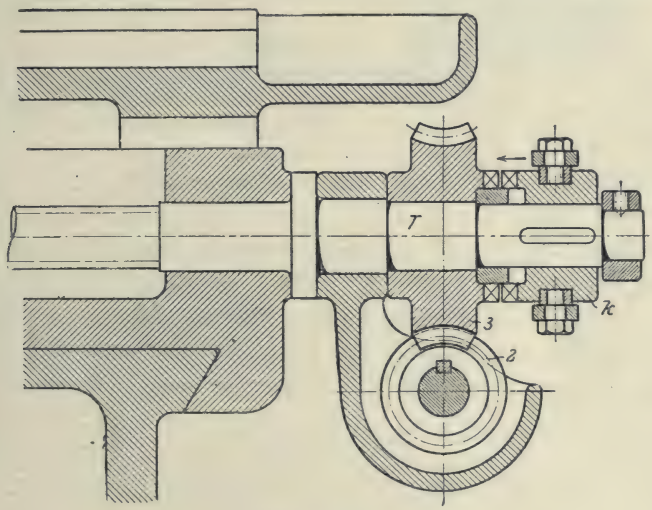


Fig. 266.
Automatic longitudinal movement mechanism of table feed of German construction.

Although in most American constructions, the longitudinal feed screw drive is usually in the middle under the table, German makers, on the other hand, generally drive it to one side by means of a worm and worm wheel. Fig. 266, gives a sectional view of such a construction. Worm wheel 3 runs idle on shaft T, but by means of the clutch K which is mounted on the shaft T by means of a sliding key, can impart motion to the feed screw.

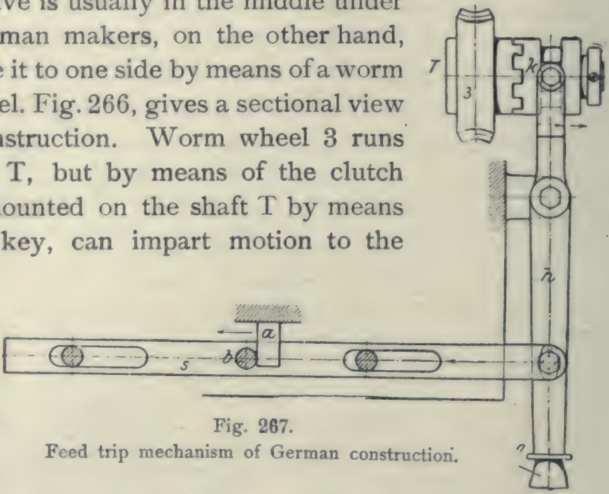


Fig. 267.
Feed trip mechanism of German construction.

Fig. 267 shows the German construction of an automatic feed trip mechanism. By means of the lever *h* the feed can be either thrown in or out by hand. To throw out the feed automatically the moveable trip button which is attached to the table, acts against the pin *b* which moves the latch *s* in the direction indicated by the arrow; this latch *s* is connected with the lever *h* and disengages the clutch of the worm wheel.

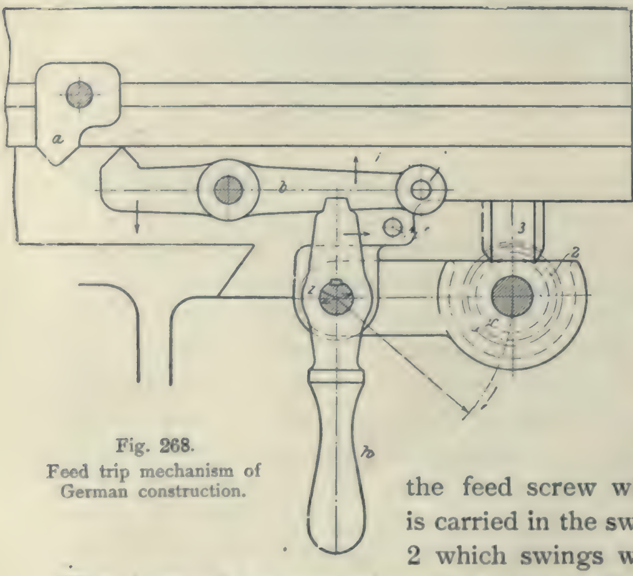


Fig. 268.
Feed trip mechanism of German construction.

In fig. 268, the worm wheel 3 is mounted on the feed screw whilst the worm is carried in the swinging bearing 2 which swings with the shaft *z*. The lever *h* is mounted on the same shaft *z*, so that it is in a fixed position with the bearing which carries the worm. This lever is locked by a notch of the lever *b*.

Lever *h* being locked, the lever *b* meshes with the worm wheel 3 by worm 2. When, however, the trip button *a* which is attached to the table, acts on the notch of the lever *b*, *h* is released with the result that the bearing with the worm drops by its own weight.

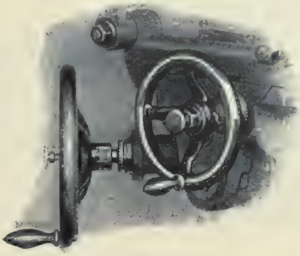


Fig. 269.
Position of B. and S. handwheels.

In connection with the feed mechanism of the milling machine, the following constructions are of special interest:

1. The position of the hand wheels for hand feed.
2. The position of the handles for disengaging the automatic feeds by hand.
3. The micrometer adjustment of the hand feed.
4. The micrometer adjustment of the automatic stops.

The longitudinal movement of the table by hand is effected by means of hand wheels or crank handles, one on each side of the table. The one on the left hand side is for regular movement, that on the right hand side for quick return of the table.

Fig. 270.
B. and S. feed trip levers.

The hand wheels for the cross and vertical feed are placed in the front of the machine in such a way that the operator can use both at the same time.

Fig. 269 shows the position of these hand wheels on the Brown & Sharpe milling machines, which is the same in most of the up-to-date milling machines. Hand wheels and not crank handles are preferable for this purpose, as the operator is then enabled to follow with his hand the circumference of the wheel, and thus keep his hand in the same position. The hand wheel for the vertical feed is placed at an angle, so that the operator can move both wheels at the same time or separately with both hands without coming in contact with either.

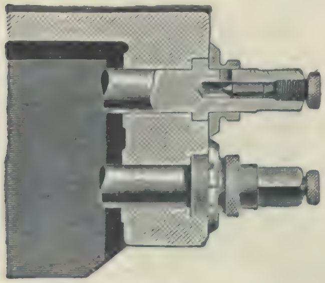


Fig. 271.
Micrometer adjustment of handfeed.

Fig. 270 shows the position of the levers for throwing in and out the automatic feed by hand as adopted for the Brown and Sharpe milling machines. They are placed, as in the case of most other makes, on the right hand side of the knee. The lever at the extreme right is used to engage or disengage all the feeds; the two others are for throwing in and out the automatic cross and vertical feeds; the lever for throwing in and out the automatic longitudinal feed is placed in the front of the table.

To ensure the perfect adjustment of the table longitudinally, crosswise or vertically, the feeds screws are fitted with bevelled graduated collars (fig. 271) indicating thousandths of an inch. These collars are loose on the feed screw spindles and are bound by a knurled screw, so that the graduation of the collar can be set at zero, thus preventing the possibility of any error being made in the reading.

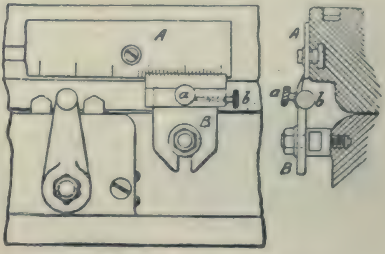


Fig. 272—273.
Micrometer adjustment of feed trip dog.

The trip dogs which disengage the automatic feed, are provided by some makers with a vernier by means of which the feed can be disengaged at a certain fixed point. Figs. 272 and 273 illustrate such a vernier as is fitted to the Brown and Sharpe milling machines. The scale A is 24″ long. This divided scale is screwed to the table, the trip groove over the entire length of the front of the table being used for this purpose.

The vernier B is screwed to the saddle, as can be seen in fig. 273. A is the clamping screw of the vernier; *b* the micrometer screw by which it is adjusted to zero. With this vernier, the automatic feed can be adjusted to thousandths of an inch.

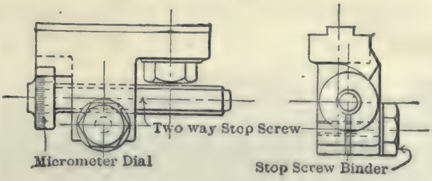


Fig. 274—275.
Micrometer stops.

Figs. 274 and 275 illustrate another construction of the micrometer table stop as used on the Garvin machines. The head of the micrometer screw, by the end of which the feed is tripped, is graduated, each division corresponding to a linear movement of the screw of $^{1}/_{1000}$th inch. The clamp in which the screw is placed is split transversely over the threaded hole and the micrometer dial can be bound by a bolt. When loosened the micrometer dial can be easily adjusted. When it has been correctly set, the bolt binds it again.

The feed most used either automatically or by hand, in the case of the column and knee type machine, is that for the longitudinal movement of the table. This movement is effected by means of a feed screw with square thread. A thread with a nut is by no means an ideal manner of table feed, especially when heavy work has to be carried out on the machine which entails a fairly heavy strain on the feed screw. The rack, as it is used on the lathe for the longitudinal move-

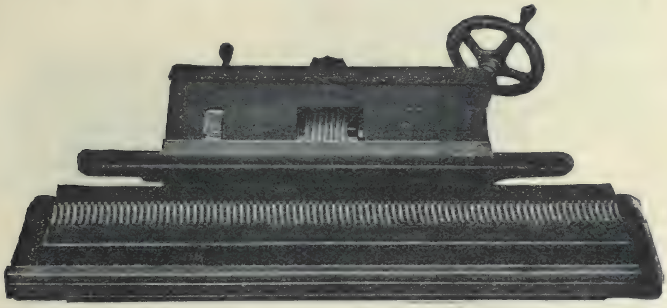


Fig. 276. Table movement by worm and rack.

ment of the carriage, is far more suitable for this purpose. In the case of the universal milling machine the use of a feed screw is *imperative* for two reasons, firstly, because it must be possible to set the table at any angle for spiral milling, for which purpose a set of mitre wheels has to be employed, one of which must swivel with the table whilst rolling over the other, and secondly, because, in order to obtain a spiral line the workpiece must rotate in a fixed ratio with the table feed and this is only obtainable with a feed screw.

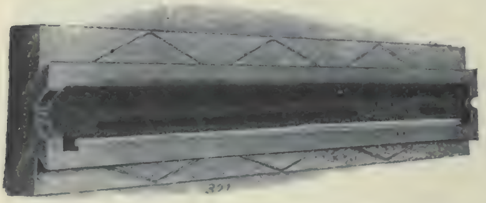


Fig. 277.
Underside of milling table.

The difference between the universal and the plain milling machine consists principally in the fact that the universal dividing head is not included in the equipment of the latter machine, nor can the table be swiveled at an angle.

Since in this case the use of the feed screw is not obligatory with the plain milling machine, the longitudinal feed is frequently effected by means of a rack and worm or pinion. Fig. 276 shows such a construction. In the illustration the underside of the table is shown to permit of the rack, which is placed underneath, being seen.

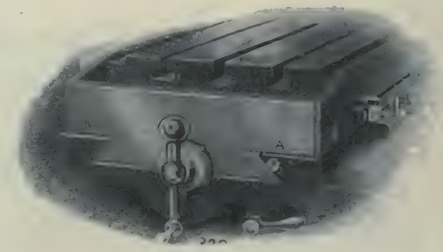


Fig. 278.
Side view of milling table showing the top.

The milling table was originally a plain casting, the top being fitted with ⊤ slots, the under side being fitted with bearings.

Owing to the increasingly heavy nature of the work demanded of the universal, and more especially of the plain milling machine (manufacturing type), the table was constructed more rigidly in order to resist twisting strains when the work is clamped to it, whilst for lubricating it was fitted with oil pockets.

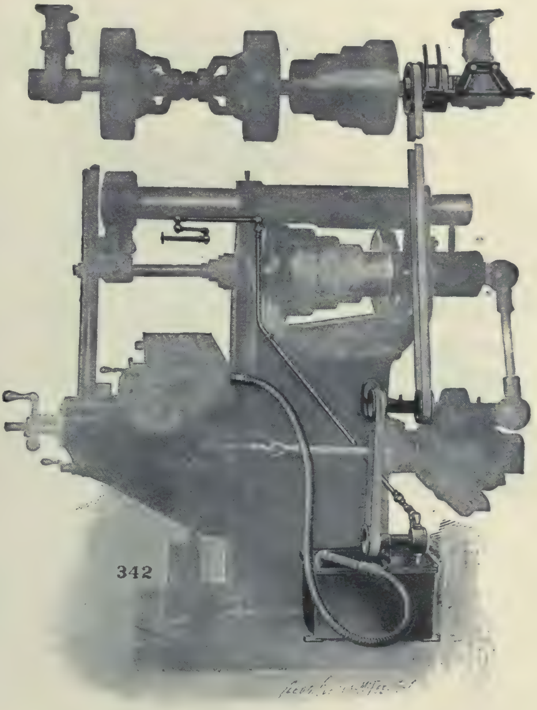


Fig. 279.
Lubricating parts.

The table of the modern milling machine is now a stout webbed casting; fig. 277 shows the underside, fig. 278 a portion of the top of the milling table of the Cincinnati milling machine.

(*e*). THE SUPPLY OF COOLING LIQUID TO THE CUTTING TOOL.

Owing to the necessity of lubricating the cutting tool and the surface to be milled, the oil pump has become an indispensable part of the milling machine. The pump brings an abundant supply of lubricant to the cutter, which collects in the oil pockets round the table, whence it is conducted through piping to a small tank where it is purified from all dirt and solid matter and then again pumped to the cutter.

The base is also provided with a raised edge so as to collect that portion of the lubricant that overflows in one way or another, as well as the chips, so as to prevent the immediate surroundings of the machine from becoming too dirty. The construction of this lubricating parts can be seen in the illustrations already given, as also in fig. 279.

(*f*). THE ARBOR SUPPORT.

In the early days, when milling was used exclusively for light work, the arbor on which the cutter was mounted, was attached in the main spindle, running entirely free and unsupported. (see fig. 280). With the development of the milling machine, it became necessary to support the end of the arbor to prevent any undue play. The top of the column was constructed as a bridge in which an arm, the front of which was curved, was mounted. Fig. 281.

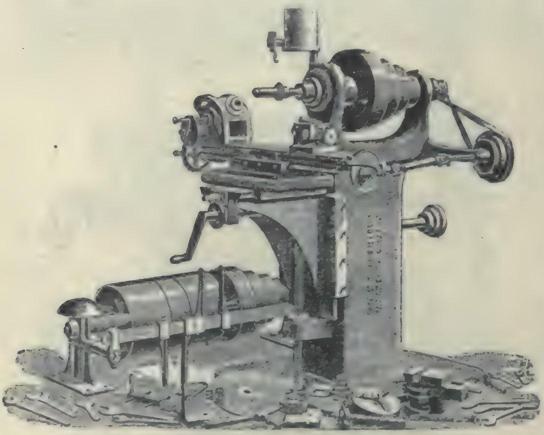


Fig. 280.
Old type of milling machine with free running arbor.

The housing for the arm was split over the entire length, the arm being clamped with two bolts (fig. 282). The curved portion, reaching to the centre of the arbor was provided with a back centre screw against the centre of the arbor: this screw was set against the arbor by hand, being afterwards clamped in the arm. Later on another slight improvement was introduced by making the pointed centre screw adjustable, after the arm had been clamped, by means of a knurled screw (fig. 281). This construction was in vogue for some considerable time.

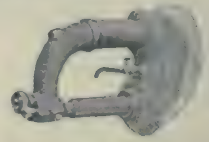


Fig. 281.
First arbor support.

The next improvement was to do away with the pointed centre. A bore in the stay of the arm directly opposite the centre of the arbor, was made to receive a split bushing, (see fig. 283). The outer end of the arbor was carried in this bush. In order to prevent any play of the arbor, the end of the arbor is made to fit the bore of the bush precisely, whilst the bush as well as the arm must be moved by hand. To avoid this difficulty the bush is split into three, being tapered in front on the outside and fitting in a cone in the bore of the stay. By means of a bolt in the front, the bush can be drawn in the tapered bore so that the

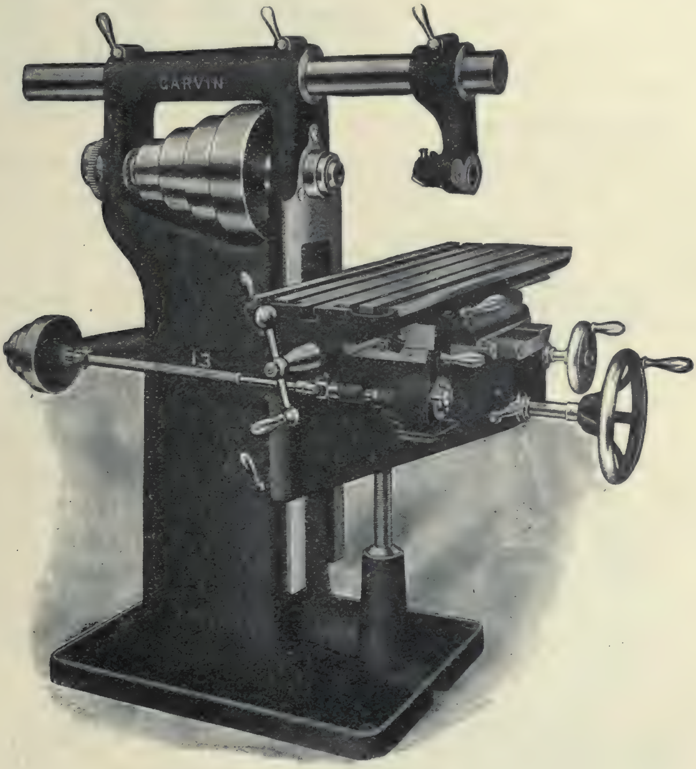


Fig. 282.
Advanced construction of arbor support.

diameter of the bore in the bush is made smaller, thus fitting the end of the arbor exactly.

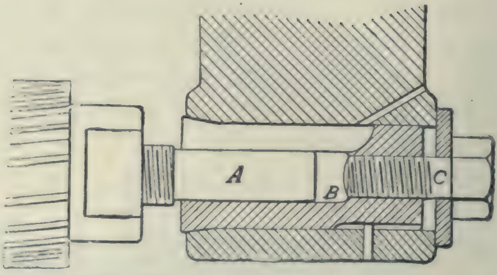


Fig. 283. Arbor support in bush.

As the work carried out on the milling machine became heavier, the resistance offered by the arm alone proved insufficient and some other support had consequently to be afforded for the arm. The form of the arm was changed from that shown in fig. 281 into a straight shaft with moveable stay which could be clamped in any position (fig. 286), to which bracings were attached which tied the overhanging arm and the knee together (fig. 285 and 287). A second stay was fitted on the arm, which could be set at any point on the arbor, giving support to the arbor close to the cutter (fig. 286). By continually strengthening the bracings, the construction shown in fig. 287 was finally arrived at, which offers a perfect resistance to the greatest possible strain. Fig. 288 shows this type of bracings on the machine.

Fig. 284. Bridge for arm.

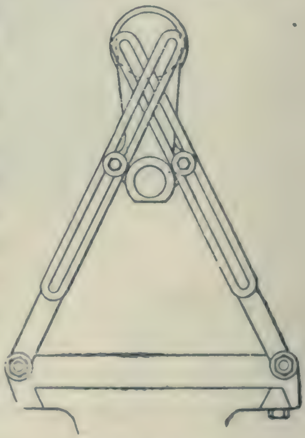


Fig. 285.
Early form of bracings.

The term *universal* milling machine sufficiently indicates that this machine can be used for a great variety of work.

By means of various attachments the attempt has been made to make the machine really "universal", so that it has been metamorphosed into a gear cutting machine, vertical miller, slotting machine, profiling machine, etc.

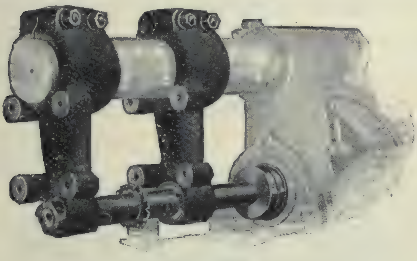


Fig. 286.
Arm with double stays.

However accurately and rigidly those attachments may be constructed, or however good their construction, such attachments can never be otherwise regarded than as *accessories*, since they are only employed in cases when there is not sufficient work to justify the purchase of a machine specially adapted for the purpose, it being but seldom that the need for such a machine is felt. In such cases, these attachments may prove an inestimable boon, still, the fact that the use, for instance, of a vertical milling attachment on a universal milling machine, will never transform this machine into a vertical milling machine, must never be lost sight of. In chapter X the principal milling attachments and their use will be dealt with.

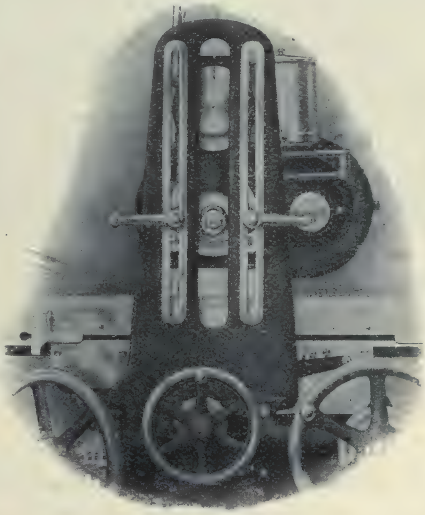


Fig. 287.
Latest form of bracings.

Whilst treating of the universal milling machine, the plain milling machine of the same type has also been described, since, as has previously been stated, the difference between the plain and the universal milling machine simply consists in the fact that certain parts, such as the universal dividing head are absent from the plain milling machine whilst the table cannot be swivelled as is, the case with the universal milling machine. All that has been said about the universal milling machine applies also equally well to the plain milling machine of the column and knee type.

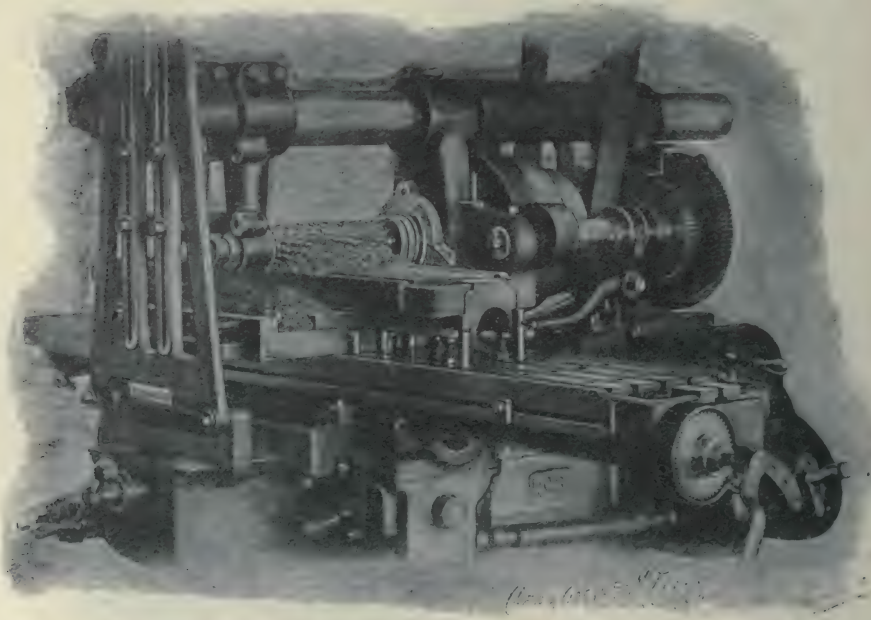


Fig. 288. Bracings placed on the milling machine.

(*g*). CONSTANT SPEED DRIVE MILLING MACHINES.

The single pulley driven column and knee type machine of Brown & Sharpe is illustrated on page 179. For the rest we have not gone further into the details of the single pulley driven type of milling machine but have simply touched it on the question of the feed and the unreasonableness of the ratio between the feed and the speed of the cone driven machine so as to give a description of this type of machine separately.

The Milwaukee constant speed drive Milling Machine.

Fig. 289 illustrates a constant speed drive milling machine built by Kearney & Trecker, which is of special interest on account of its original disign. The drive is much lower on the column than is the case with any other type of milling machines, with the result that there is much more room left in the column for the distribution of the gearing for the speed as well as for the feed so that only one box is really outside the column. This gives the machine a far less complicated appearance. There are two times three crank handles for changing the feed and the speed. As in the case of the cone driven milling machines, the feed is *not*

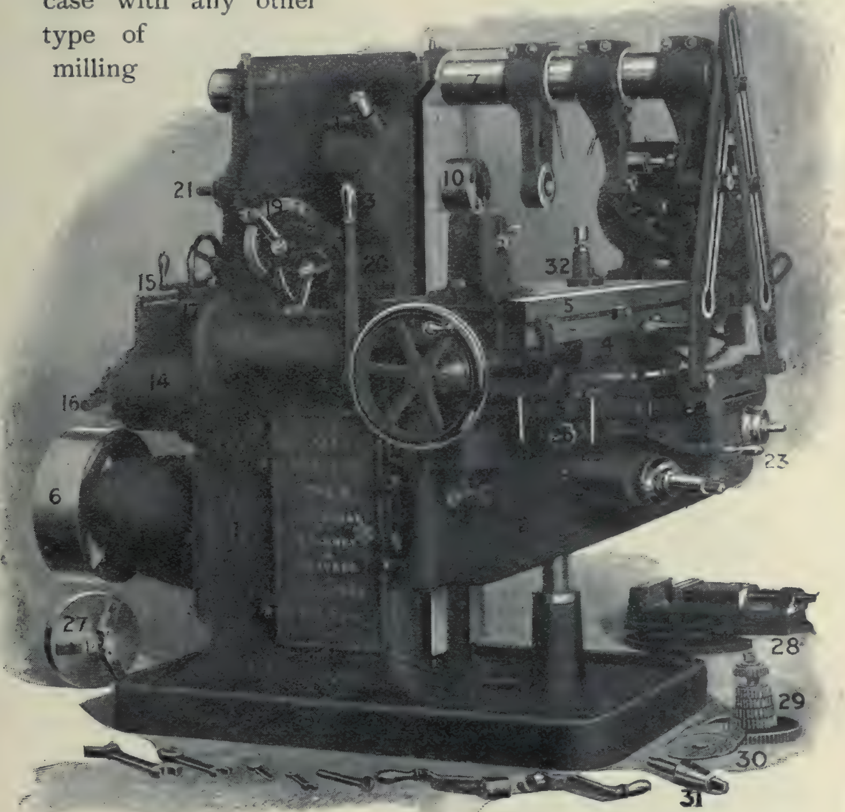


Fig. 289. Constant speed drive milling machine.

expressed per revolution of the cutter but per unit of time. The column and knee, i. e. the two principal parts which have to withstand all the working strain are box sections with as few openings as possible.

It will be seen from fig. 290 that the knee is almost a closed box. This feature of the box knee completely closed is one of no little interest; on the contrary, it has of late come to be regarded as of the utmost importance and an essential feature in the good construction of milling machines. It frequently happens that cuts have to be taken with the

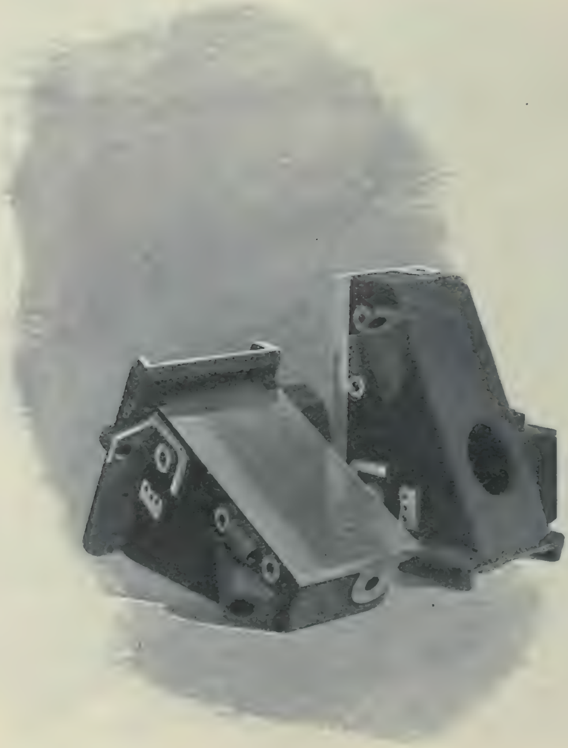


Fig. 290. Box knee with closed top.

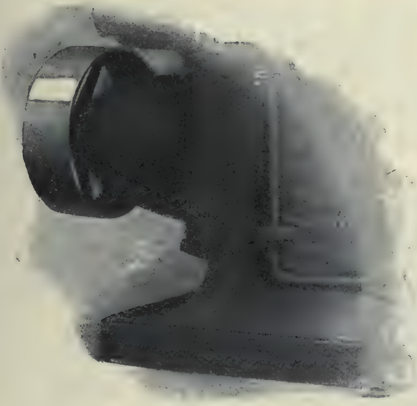


Fig. 291. Standard drive.

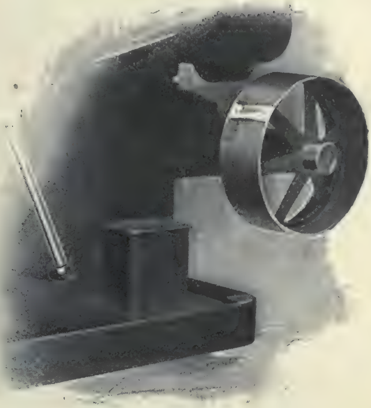


Fig. 292. Right angle drive.

table heavily loaded drawn out far from the column, especially on universal machines when cutting spirals, and the saddle must then be run out to prevent the table striking the ways on the column. The drive of the machine under review is obtained from a single pulley of ample diameter running at ample constant speed. Another feature of the constant speed drive is that practically without the necessity of making any change, the machine can be either right angle driven or driven by motor by a simple alteration of the bracket. Fig. 291—293 show how easily the three different drives are shifted. They are interchangeable without any further preparation or change of the machine itself. Fig. 294 gives a

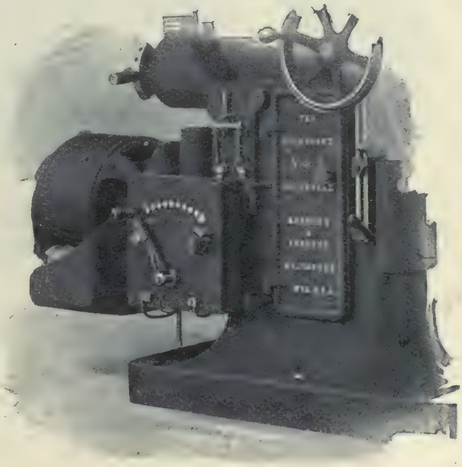


Fig. 293. Motor drive.

sectional view of the plain machine, showing all the gearing for speed changing and parts of the feed gearing. Pinion 9 part of pulley shaft 1 engages with a sliding clutch gear 10 turning idle on the shaft 2 and connected with the starting lever 13 to be seen in fig. 289. The opposite clutch gear

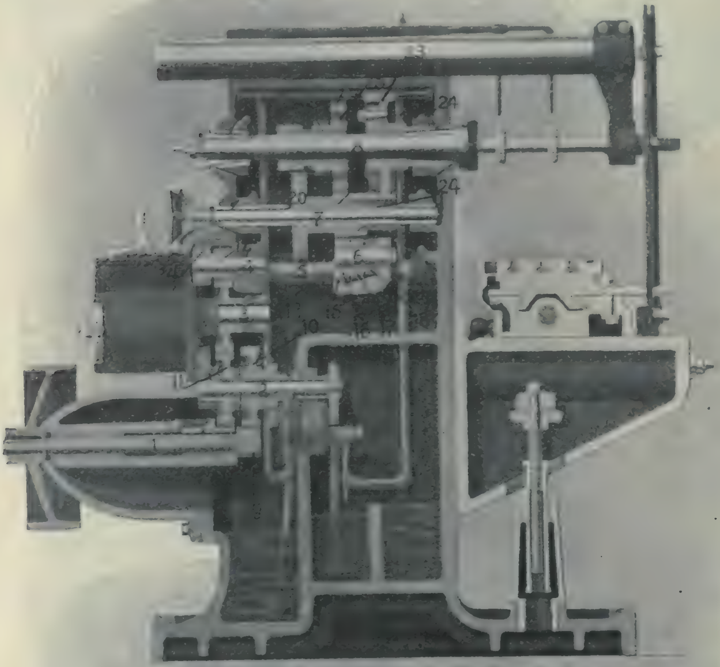


Fig. 294. Sectional view of column and knee.

11 on the same shaft 2 is engaged when the machine is started. This gear drives gear 13 on shaft 3 at the back of the feed box. A jaw clutch is used for starting and stopping the machine, as owing to their great simplicity and the fact that no adjustment is ever necessary, and as they revolve at a comparatively low and constant speed no

shock occurs when the gears are engaged. Gear 13 on shaft 3 drives the main driving shaft 5 which in turn through the sliding gear 15 on shaft 5, fig. 297 drives the three-step tumbler gears 16 to 18 on shaft 6 by means of which the speed is varied as follows:—Shaft 7 below the main spindle carries two gears of different diameter, viz:—19 and 20, and the tumbler with the wheels 16 to 18 is so arranged that each of these wheels can be engaged with each of the two gears 19 and 20 so as to give *six* speed changes to shaft 7. These again are multiplied by three through the sliding sleeve gear on the main spindle which is made to engage with the main spindle drive gear 23 or either of the two gears 19 or 20. In this manner *eighteen* speed changes are obtained in geometrical progression, the ratio used being 1,225, and any speed multiplied by this ratio gives the next higher speed. The speed changes are effected by the crank handles 19 and 18 turning over the plate and by the tumbler handle 17, all of which are to be seen in fig. 289. The tumbler handle 17 moves the tumbler cone gears 16 to 18 shown in fig. 294 and 297, whereas the crank handle 19 moves the gears on the main spindle and the crank handle 18 moves the tumbler gears in an axial direction. Fig. 295 illustrates the back of the column plate over which these crank handles move and from this it will be seen that at the back there are two gears each meshing in a rack, one provided with a horizontal and the other with a vertical

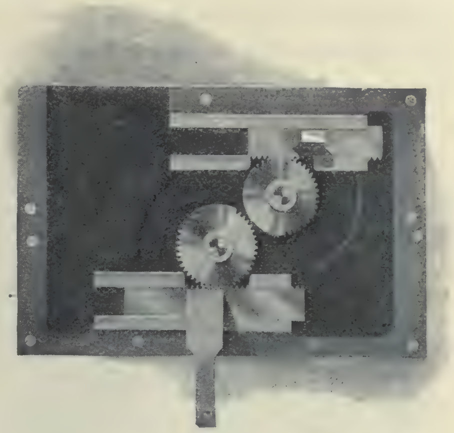


Fig. 295. Column plate—backside.

finger, the first one engaging the groove of the main spindle sleeve 21 and 22, the other one engaging the tumbler. On the front side of this plate there is an index plate, fig. 296, which shows the number of revolutions for a given speed of the main drive for each position of the handles.

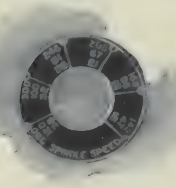


Fig. 296.
Speed index plate.

Fig. 297 shows a horizontal section over the column and through the three-step tumbler gear with wheels 16 to 18 and gives a clear view of the construction of this part. This cone gear revolves on stud 6 firmly planted in the swinging frame that is securely supported on both sides of the tumbler; on one side by the driving shaft, which for this purpose is larger in diameter than is actually required and on the other side by the teeth of the long pinion meshing the teeth cut in the segment of the frame and by means of which it is made to engage with the gears above. Fig. 297 also shows how the spindle reverse is effected. The sliding gear

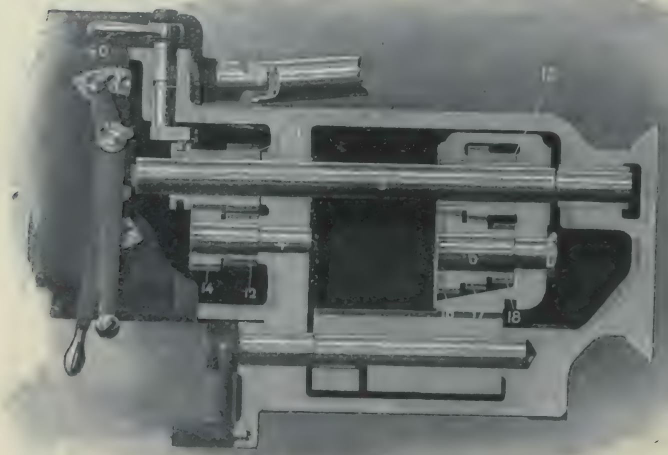


Fig. 297. Tumbler support and spindle reverse.

31 on the driving shaft engages, for right hand rotation, with gear 13 on the feed box shaft 3 fig. 294 which also engages the smallest step 12 of the reversing idlers 12 and 14. When the sliding gear is in mesh with the large step 14 of the idler, it is out of mesh with gear 13 and the spindle runs left hand.

There is a means of locking the spindle when tightening the arbor nuts. This locking plunger 12 is to be seen in fig. 289 and is cut as part of an internal gear of the same pitch diameter as the main spindle gear so that when engaged with gear 23, fig. 294 the teeth fit in all their curve throughout a wide arc and the spindle is held securely. The starting lever is automatically locked out when the plunger is engaged in the main gear.

The feed is driven from the constant speed gear 13 on shaft 3 previously mentioned as part of the drive train; the amount of power going into it automatically depends on the conditions of the cut. Twelve feed changes are provided by the mechanism in the feed box similar to that shown for the drive. These feed changes are also in geometric progression, the ratio being 1.35. The slowest feed is $\frac{1}{2}$ inch, the fastest 16 inches per minute, and, as mentioned above, these have no reference to the speed of the main spindle. Fig. 298 gives a top view of the feed gear box with index plate showing the feed for any position of the handles. As previously stated, the change of feed is effected in a similar manner to the change of speed, viz:—by three handles, two on the top of the feed gear box and one at the side, (marked 16 in fig. 289), acting on a tumbler gear cone. The foremost handle in fig. 298 gives three speed changes, fast, medium and slow; the rearmost handle giving four other changes, making a total of twelve feed changes in all. By this means finer feeds are provided for small cutters at high rotative speeds and coarser feeds for large cutters at low rotative speeds than can be obtained by any other system of feed driven from the main spindle regardless of how many changes are used. The power is carried from the feed box forward by a universal joint shaft.

The centre block is square and forms an oil reservoir to keep the parts thoroughly lubricated. The drive of the feed screws does not differ so much from what has already been described as to require any repetition. There is, however, an originality in connection with this machine which deserves special mention and that is, that the vertical, cross and table

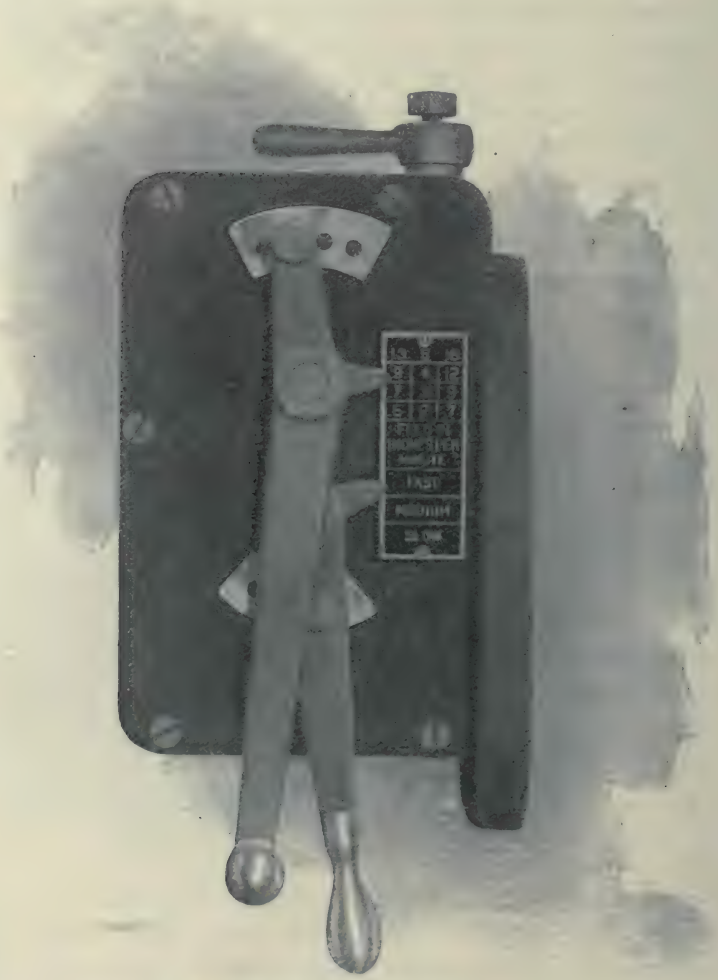


Fig. 298. Feed box—top view.

feeds are so arranged that no two can be engaged at the same time. The sectional view of the knee given in fig. 299 shows how this is accomplished. The shaft in the upper right hand corner is for the table feed and the clutch on this shaft is engaged only when the plunger at the left is in the central position, at which time the double rocker arm controlling the cross and vertical feeds is locked by this plunger. In order to throw in either of the other feeds, this plunger must be set to one side of the lever through which it passes and this disengages the table feed clutch and makes possible the engagement of one only of the other feeds according to which way the plunger is moved, the knee being plainly marked to show which feed will be engaged.

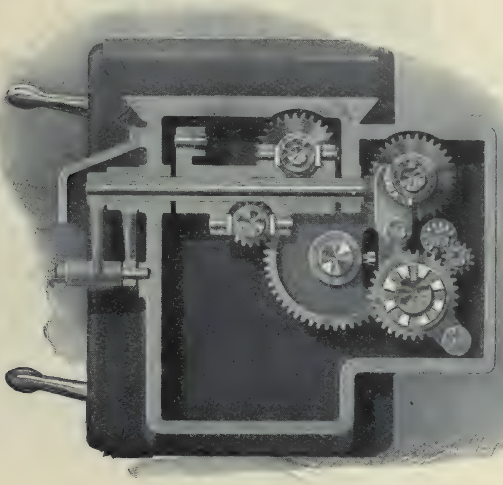


Fig. 299. Feed interlocking device.

Careful attention has been devoted in this machine to the question of lubrication of the running parts as well as of the cutter and the work. The bearings, driving parts and gears are flooded with streams of oil that is pumped with a simple spur geared pump from the reservoir in the base and to the rear of the machine, and distributed to all gears and bearings by means of a perforated pipe at the top. After flowing into the pockets arranged to supply the spindle bearings with oil, it overflows and cascades downwards, overflowing each pocket and sending a steady stream through each bearing. There is another reservoir in the base, also with spur geared pump. specially for lubricating the cutter. This cutter lubrication is guided by piping in the interior of the column extending only a short distance out of the column to the cutter. From the sectional view given in fig. 294, it will be seen that after the lubrication has reached the table and has been purified, it returns through an internal channel to the table base, thence through piping to the rear of the machine and from there it is conducted to the reservoir where it undergoes further purification. The construction of this machine as regards lubrication is certainly one of its most interesting features and proves that its designer was fully aware of how much depends upon ample lubrication not only of the running parts but also of the cutter.

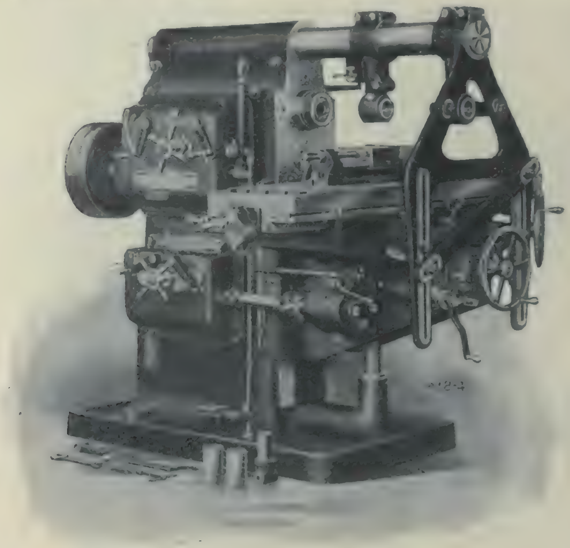


Fig. 300. Cincinnati constant speed drive milling machine.

The Cincinnati constant speed drive milling machine.

A front view of this machine is given in fig. 300. The main driving pulley of the machine is not mounted directly on the driving shaft but is journaled on a bracket bolted to the column. The entire belt pull is therefore relieved from the driving shaft and taken up directly by this bracket. A disc friction clutch connects the driving pulley to the driving shaft and the machine is started and stopped by operating this clutch by the lever located at the front of the column. When the clutch is out, every part of the machine is stopped with the exception of the driving pulley. When the clutch is thrown in, power is transmitted through the main driving shaft and the tumbler gears shown in fig. 301, and the driving gears shown in fig. 302. Sixteen changes of speed are provided on this machine, viz:—two series of four each through the back gears and two series of four each direct through the sliding gears. The sliding gears are connected together on a large sleeve, (fig. 302), which

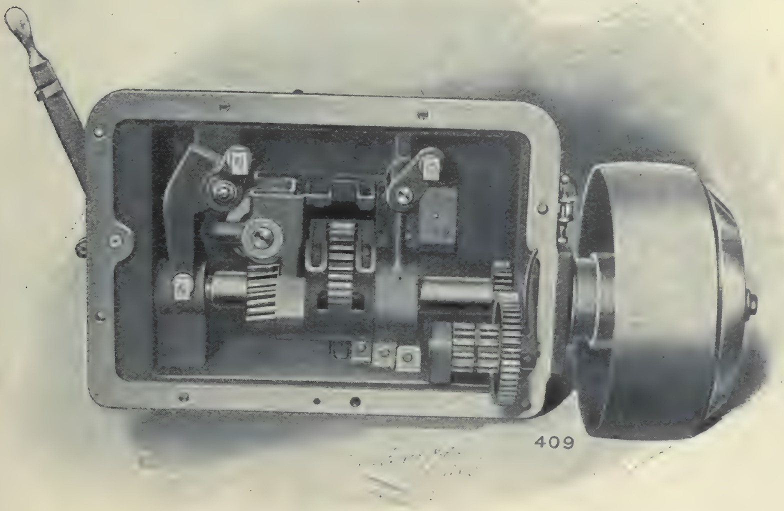


Fig. 301. Inside of spindle drive box showing driving shaft, tumbler and chain wheel for driving feed from constant speed shaft.

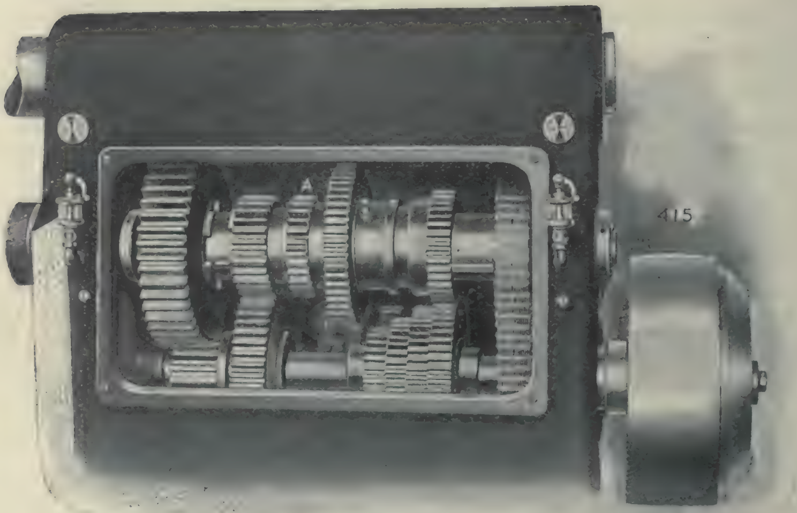


Fig. 302. Driving gears. Showing feed driven from spindle.

in turn slides on a second sleeve mounted on the spindle. Transmission is therefore never through the length of the spindle but at all times through these sleeves to the face gear either direct through the clutch or through the back gears. The drive is, therefore, always through a point immediately to

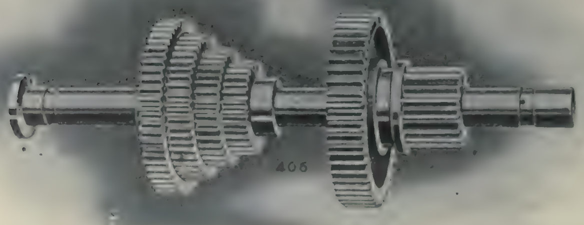


Fig. 303. Cone and backgears on their shaft.

the front box. The spindle is never subjected to torsional strain throughout its length, but bending strains only, thus eliminating torsional vibration in these parts. The small gear "A", (fig. 301), is never used for transmission but merely serves as a pilot when throwing the back gears into engagement; when the back gears are not in use, they are entirely out of mesh and do not revolve. There are at no time any gears in mesh except those actually used for driving. The operation of throwing the back gears out and engaging the clutch on the driving sleeve with the face gear is accomplished by a single movement of one of the speed change levers. There is no position of the back gears in which the gear train is locked. Fig. 303 shows the cone and back gears, which are bronze bushed, mounted on their shaft. This shaft does not revolve and is, therefore, not subjected to torsional strains but bending strains only, thus lessening the possibility of vibration in these gears. Fig. 304 shows the main driving gears mounted on the spindle. It also shows the lock nut immediately at the side of the front

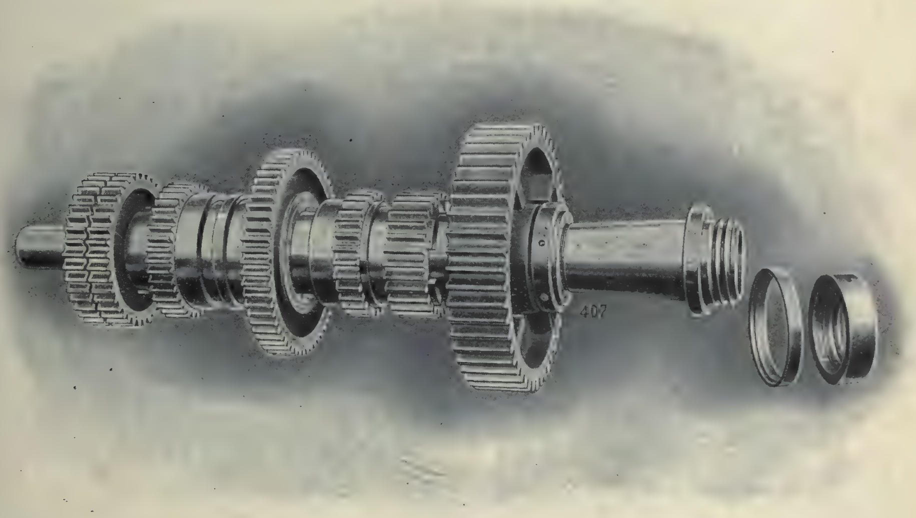


Fig. 304. The spindle and driving gears.

bearing by which the spindle may be closely adjusted to take up wear. This illustration further shows the liberal proportions of the driving gears, all of which are of steel, of coarse pitch and capable of transmitting the full power of the driving belt under all conditions.

The tumbler construction which is to be seen in fig. 301 and 305 is so arranged that the operation of speed changing also securely locks the tumbler through its frame to the slide of the main frame of the machine from which the tumbler is supported. The swinging frame containing the gears is mounted in the main tumbler frame and rocks on the trunnions "D". It is operated by the turnstile on the outside of the column through spiral gears shown in the illustration, one of which is mounted directly on the trunnion of the swinging frame. Its operation is as follows: — By turning the turnstile to the left as far as it will go, the tumbler gears are brought out of mesh; then by a lateral movement, the entire tumbler is shifted to the desired position, and by then turning the turnstile to the right, the tumbler is again engaged with the desired gear of the cone. The stop pins "P" against which the lug on the swinging frame presses, govern the proper meshing of the gears. It will be seen that after the gears are in mesh, if the turnstile is turned further to the right, the swinging frame, the tumbler frame and the spiral gears act as a system of

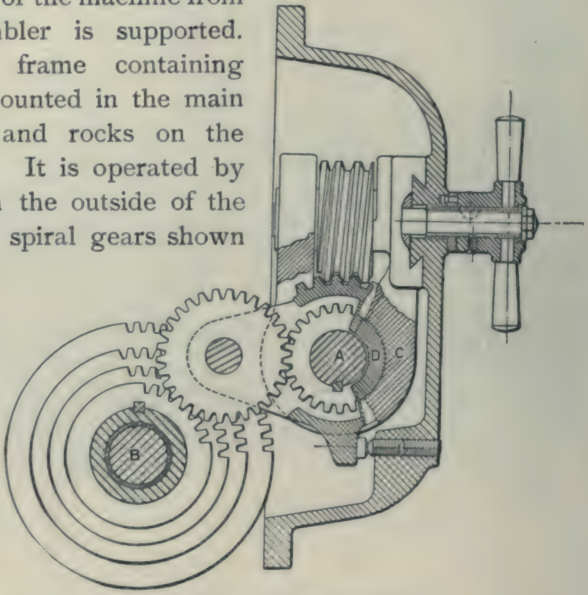


Fig. 305. Section through tumbler.

levers and screw which lock the tumbler frame securely to its slide on the main frame of the machine, thus holding the support for the tumbler gears as firmly as if it were bolted in place. On further reference to the illustrations it will be seen that the entire tumbler mechanism is carried on its slide on the main frame of the machine. The main driving shaft "A" has clearance in the tumbler frame so that at is not subjected to strains due to either the weight of the tumbler, the thrust of the cone gears while driving, or any of the strains due to locking the tumbler in position.

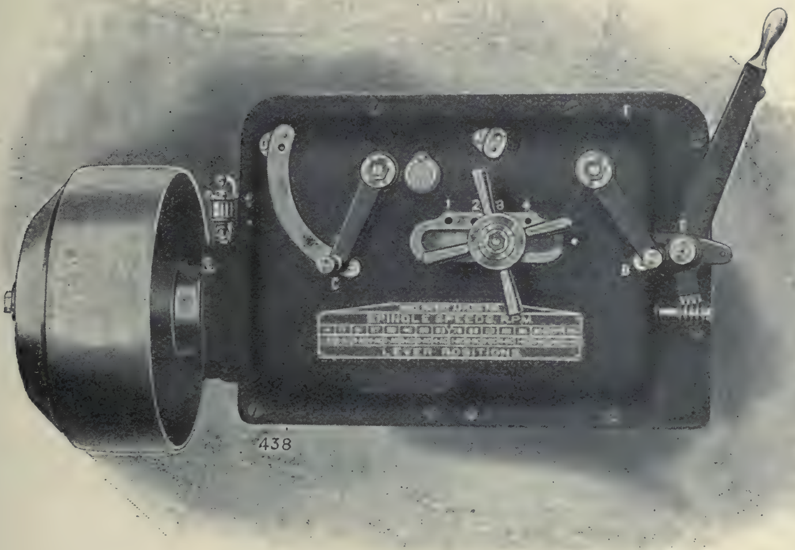


Fig. 306. Outside of speed change box.

From the foregoing it will be seen that none of the main shafts are ever subjected to both bending and torsional strains; the back gear shaft and the length of the spindle being subjected to bending only and the main driving shaft to torsion only. By means of this construction in connection with the locked tumbler bracket, all cause of vibration in the main driving gears has been eliminated.

Speed Changing. This is effected by means of the two levers and turnstile shown in fig. 306. The lever positions are marked "A B" and "C D" and the turnstile positions are marked 1, 2, 3 and 4. Care has been taken to prevent the possibility of any confusion to the operator in turning the back gears in or out, in setting the levers to the right or left, fast, medium or slow. In the same way, to determine at what speed the machine is running, the turnstile is set at 3 with one lever at "B" and the other at "C". The position is, therefore, 3—B C, which on reference to the index plate corresponds directly to 115 revolutions per minute.

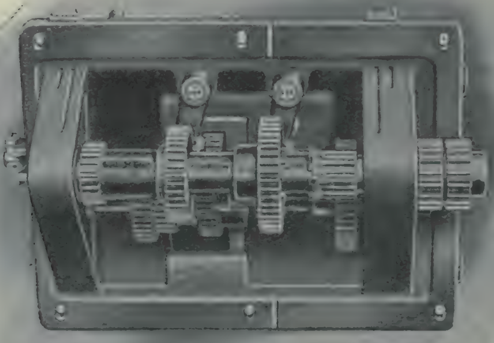


Fig. 307. Interior of feed box.

The machine having been stopped to change the speed, the gears may interfere when shifting the levers and it is therefore necessary to revolve them slightly. This is done by the treadle shown in the illustrations. It is connected to the main clutch lever and operates on an auxiliary disc clutch. The operation of speed changing, therefore, consists of selecting the lever positions for the desired speed, setting the turnstile in position, moving the change lever as far as it will go and then, if the gears interfere, exerting a slight pressure on the treadle. This brings into play the auxiliary disc clutch which starts the gears gently so that the lever can be moved the remainder of the way.

Feed Mechanism. All the feed changes are contained in the feed box itself, the interior of which is shown in fig. 307. This shows all the gears connected with feed changing. The feed changing is similar to that of speed changing except that the treadle is not used as the machine is not stopped for feed changing. Fig. 308 gives an external view of the feed box. From the illustration in fig. 300 it will be seen that this box is located high above the floor, which adds greatly to the convenience of the operator. There are 16 changes of feed, which can be changed from the one to the other throughout the entire series by a single movement of the feed levers. Feed changing can be best done whilst the machine is running. The feed gearing is driven by a slow speed silent chain. The feed which can be read in inches per minute ranges from ½ inch to 20 inches

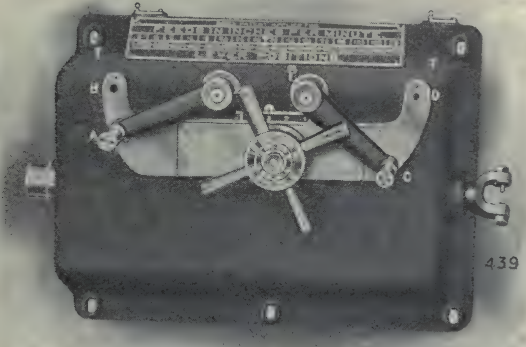


Fig. 308. The feed box.

per minute table travel. The feed is driven from the constant speed shaft by the chain wheel to be seen in fig. 302.

For the general construction of knee and table, we refer the reader to the general description of the column and knee type machine already given. In general the various parts of the constant speed drive milling machine are constructed much heavier and far more substantially than before, though it does not differ so much in design as to necessitate a detailed description being given.

CHAPTER IX.

Different types of milling machines.

(*a*). PLANO-MILLERS.

As soon as the metalworking industry had learned to appreciate the utility of the milling cutter for metal working, the idea was quickly seized upon of carrying out on the milling machine a great deal of the work previously performed on the planer, viz:—the machining of large surfaces, or to be more accurate, to supercede the planing tool by the milling

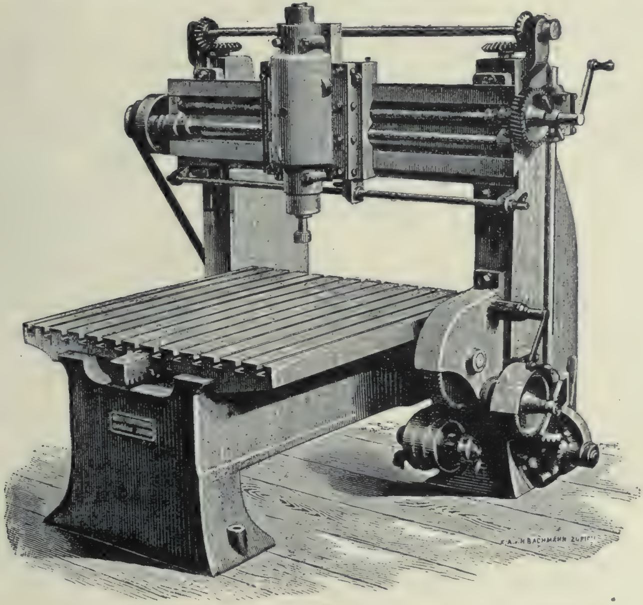


Fig. 309. Early form of plano-miller with vertical spindle.

cutter and whilst preserving the original type, the planer was transformed into a milling machine.

Of nice form and design, these machines certainly were not. Figs. 309 and 310 illustrate such machines of the planer type, the one arranged for vertical and the other for horizontal milling.

As far as the plano-miller is concerned, too much was expected of this type after the first successful trials. It was thought that the planer would soon be done away with for good and all, at any rate as far as the machining of large surfaces was concerned. Experience has proved the reverse. As a preparatory machine, as also for machining large workpieces, the plano-miller is eminently adapted, but for accurate finish of long and large workpieces, the planer proved and still proves to be indispensible.

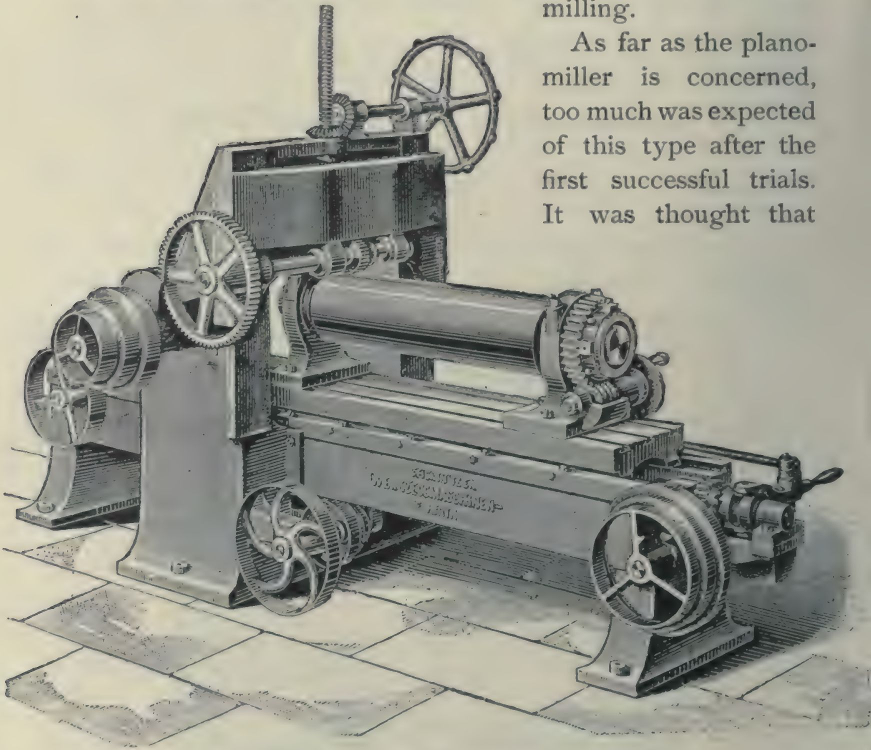


Fig. 310. Early form of plano-miller with horizontal spindle.

One of the first to put a plano-miller of good design on the market, was Lincoln, who built the milling machine called after him, (fig. 311), which at the present time is copied, with certain slight alterations, by a large number of makers. It is specially adapted for the slabbing of work-

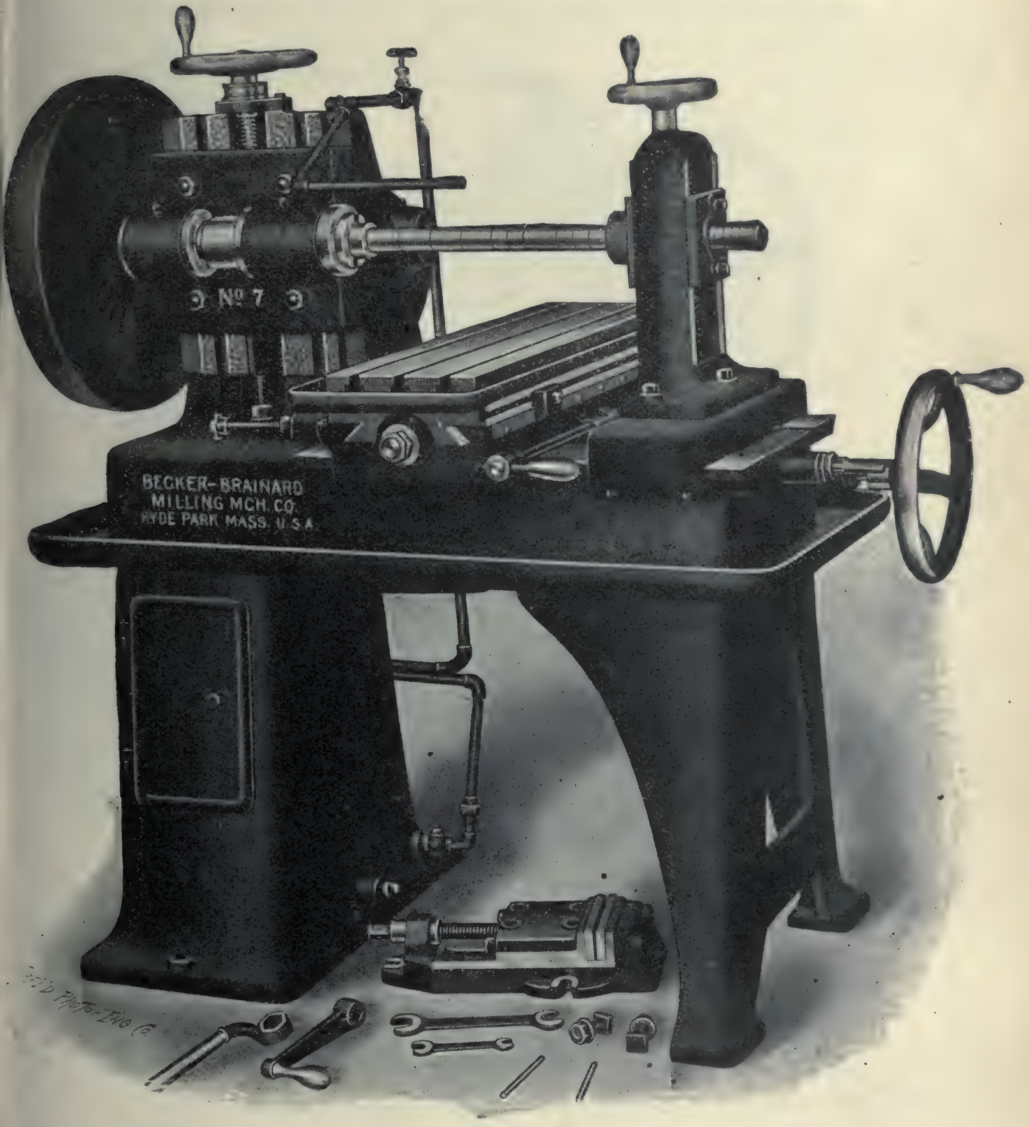


Fig. 311. Lincoln-type of milling machine.

pieces of not too large dimensions and only for milling in a straight line, either horizontally with milling cutters on the arbor or vertically with end or face cutters. The saddle, carrying the main spindle is vertical adjustable by hand over a short column forming one casting with the bed. The saddle bears on this column by means of broad faces which ensure great rigidity. The cone pulley for the drive is at the rear, the spindle being driven by means of gearing. As the ratio of speed of the cone pulley and the main spindle is large, a high belt speed is obtainable, which consequently

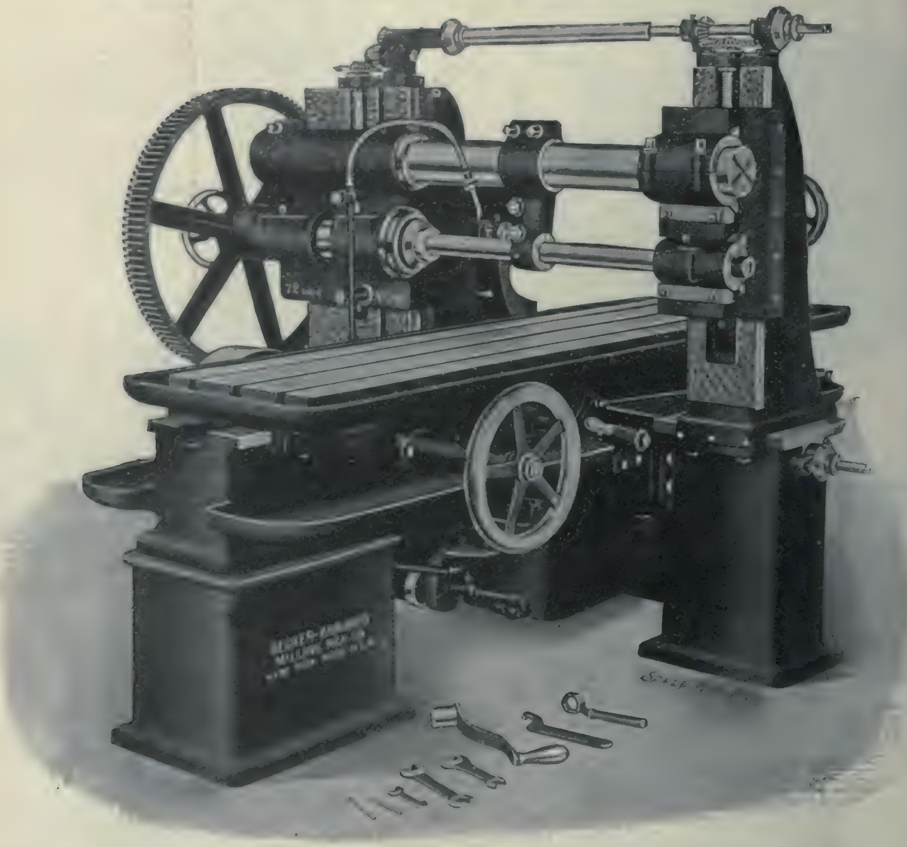


Fig. 312. Plano-miller.

increases the power the belt can transmit and as a rule heavy cuts can be taken by this type of machine. The spindle is supported in a vertically adjustable tail post.

The carriage has a transverse adjustment over the bed by hand, the table has longitudinal power feed, i. e. rectangular to the main spindle. The principle of this type of machine is that of a powerful, simple tool with as few working parts as possible, suitable for milling plain surfaces.

From this type of milling machine, a large number of other varieties have been devised.

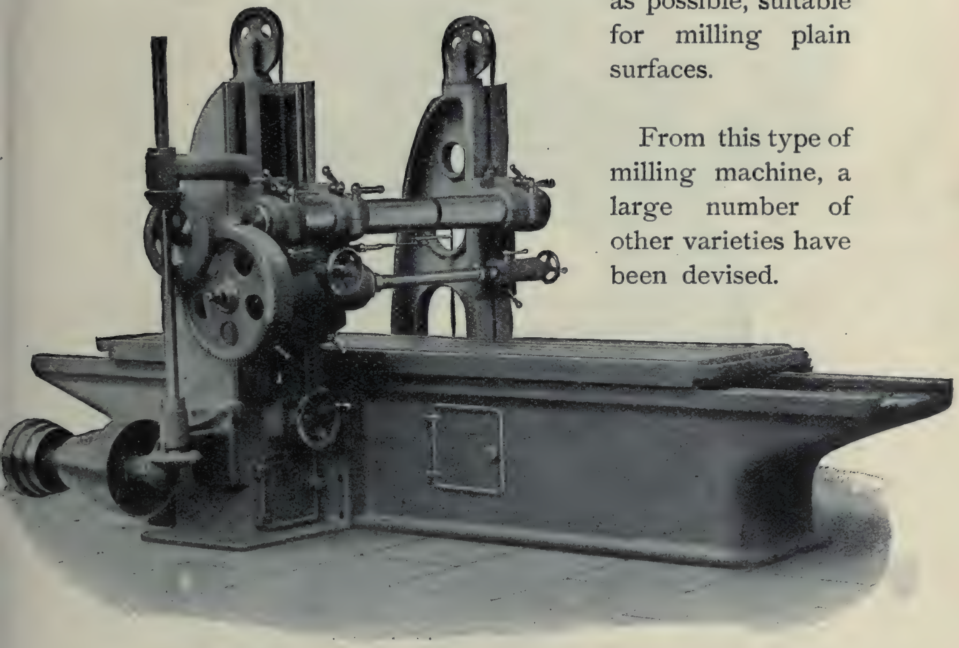


Fig. 313. Plano-miller of German make.

In the machine shown in fig. 312, the types illustrated in figs. 309 and 310 can be easily traced, though at the same time, the general form of the planer is still discernable.

The table of this type of milling machine is moveable only rectangularly to the spindle, whilst the auxiliary column is adjustable crosswise over a short distance parallel with the spindle. The main saddle on the column and that on the auxiliary column are tied by a 5 inch arm on which an auxiliary stay is mounted, thus making it possible to support the arbor firmly between two bearings.

In still closer resemblance to the planer, the general form of the machine shown in fig. 313 can scarcely be distinguished from it. The drive is derived from the foot of the bed, the main spindle being driven by means of a double set of mitre gears and a double set of spur gears. Work-pieces up to 8 ft. in length can be handled on this machine.

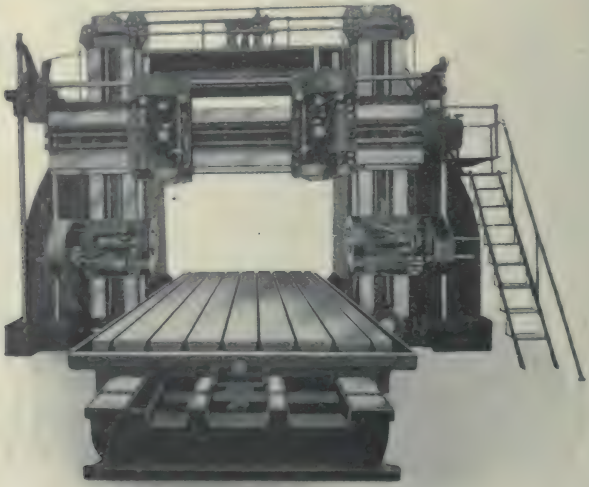


Fig. 314. Ingersoll plano-miller with four spindle heads.

Of the comparatively few makes of heavy plano-millers, those of the Ingersoll Milling Machine Co. certainly deserve particular attention. This firm builds plano-millers of such a size that they may justly be termed giants of their sort. They vary from the small Lincoln type of machine to those with 4 spindle heads, two horizontal and two vertical, in a variety of combinations.

Fig. 314 shows one of the Ingersoll machines which gives some idea of the enormous proportions in which this type of milling machine is built. The two heads on the housings can work either separately with face mills or be fitted with an arbor for milling large surfaces with a slabbing cutter. Furthermore, both heads on the crossrail can be fitted with face mills. The weight of the machine illustrated in fig. 314 is over 300.000 lbs.

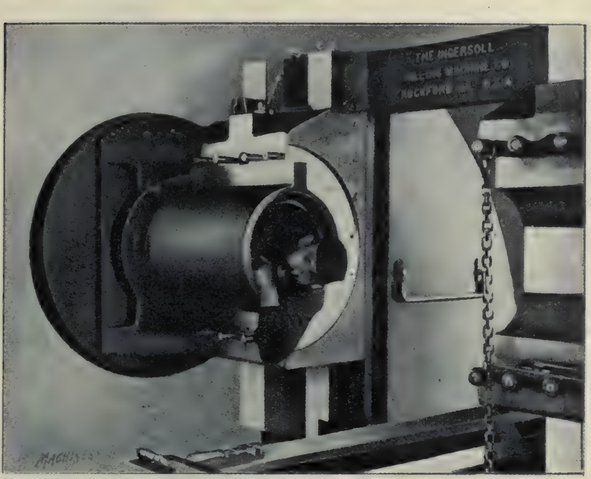


Fig. 315. Spindle bearing of Ingersoll plano-miller.

Fig. 315 affords a striking example of the enormous dimensions of the various parts of this machine, a workman being seen in the spindle bearing, the cover of which has been removed.

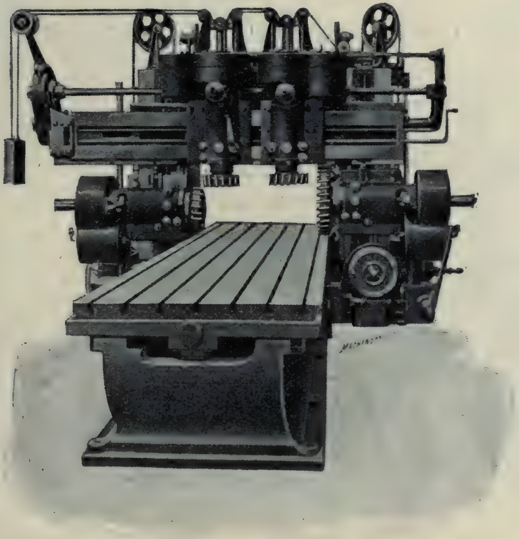


Fig. 316. Ingersoll plano-miller with four spindle heads.

Two workpieces can be milled simultaneously on this machine, whilst face mills with a diameter of 36 inches can also be used. Fig. 316 shows such a machine with face mills mounted on the spindles. For milling the ends of long workpieces, these machines are built with a removable housing (fig. 317), so as to permit of the milling of workpieces of unlimited length.

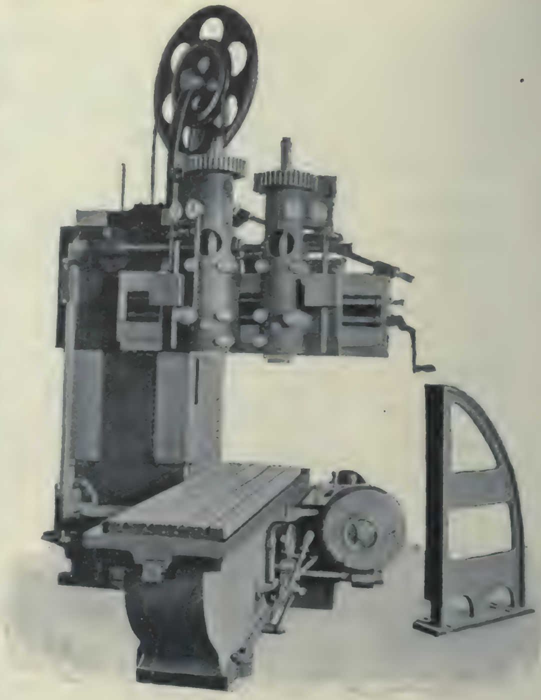


Fig. 317. Open-side plano-miller.

The machine illustrated in fig. 316 is arranged for belt drive, but by far the greater number of these large machines are arranged for direct motor drive, which, for the larger types absorbing 60 and more H. P., is practically a sine qua non. Fig. 318 shows the manner in which the motor is coupled to the machine.

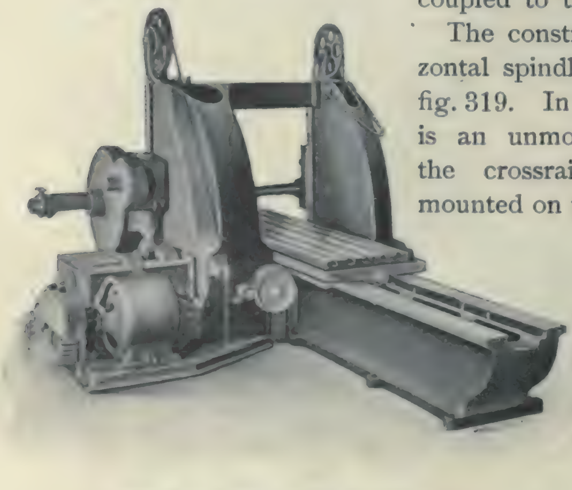


Fig. 318. Motor-driven plano-miller.

The construction of the horizontal spindles is illustrated in fig. 319. In this illustration A is an unmovable bearing on the crossrail, B the wheel mounted on the spindle, causes it to rotate, C a movable double bearing on the crossrail, D the parallel portion of the spindle, which slides in the

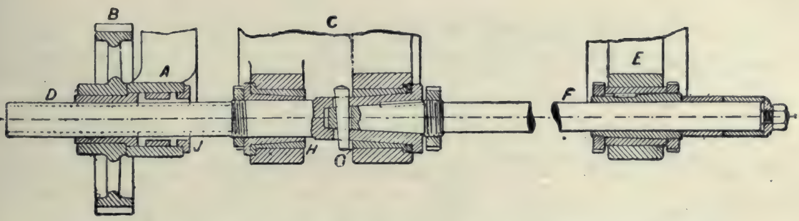


Fig. 319. Section over the horizontal spindle of Ingersoll plano-miller.

bearing of A, when C is adjusted longitudinally over the crossrail. The arbor support E can also be adjusted on the crossrail, so that the distance between C and E, between which the cutter is mounted, can be adjusted according to the face of the cutter. The bearings of C consist of two separate, adjustable reversed tapered boxes. Both boxes are adjusted on the spindle by the lock nut at the left hand side. These boxes are of cast iron. The bearings are of bronze. The milling arbor fits in the main spindle with a cone, being tightened by a key between the bearings.

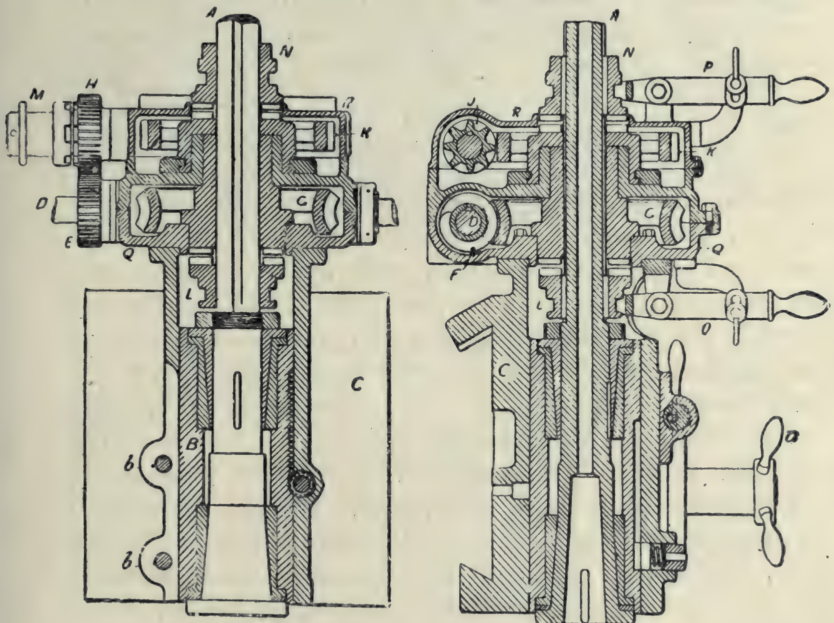


Fig. 320. Fig. 321.

Sections over the vertical spindle of Ingersoll plano-miller.

The vertical spindles of the Ingersoll plano-millers are so designed that the spindle speeds can be changed by clutches from fast to slow and *vice versa* in such a manner that the spindles are driven by a worm and worm wheel or by spiral gears. Figs. 320 and 321 represent two vertical sections.

The hollow spindle A has its bearing in a sleeve B vertically adjustable in the saddle casting C, which traverses the crossrail. The sleeve B is adjusted by rack and pinion, operated by the turnstile *a* and clamped by the screws *b*, *b*.

The rotary movement of the spindle A is derived in the first place from the horizontal shaft D, splined to drive the spur wheel E and the worm F. The worm F engages with the wormwheel G, whereas E drives the spiral gears by H which is on the end of the spindle that carries the small spiral wheel J, engaging with the large wheel K. The wheels G, H and K all run idle on their spindles and are engaged by the clutches L, M, and N. L and N are handled by the locking levers O and P. The worm and spiral gears are covered by the casings Q and R.

(*b*). ROTARY MILLING MACHINES.

During the last few years the milling machine shown in fig. 322 and known as the rotary miller has appeared as a very serious rival to the lathe. Not that it can ever take the place of the lathe for general lathe work, as it is only suitable for workpieces which owing to their special form are adapted to this type of machine and even then it can only be used to advantage for repetition work. In the case of the rotary miller, "repetition work" need not necessarily be taken to mean that thousands of workpieces of identically the same form have to be handled. For a small number of workpieces which are never likely to recur, neither the setting up of the machine itself nor the cost of the special tools required would prove remunerative. Where a few score of workpieces have to be machined, the use of this type of machine, even when those pieces are never likely to occur again, would prove remunerative, but even so the profit derived from such a small number with regard to the same work out carried on the lathe, is not so great as to compensate for the not inconsiderable expense of the special cutters which could not be used subsequently. Should the same workpieces recur from time to time, a few score of such workpieces would make the machine pay for itself in addition to covering the cost of the cutters, whilst in cases where larger numbers have to be machined, the cost of production on the rotary miller will prove to be considerably less than if the same work were carried out on the lathe. In this connection, the fact that the rotary miller requires but little attention must not be lost sight of, so that one workman can look after a number of such machines or superintend one or two rotary millers simultaneously with other machines. Work carried out on the rotary miller has not such a finish and degree of accuray as to permit of the performance of work requiring absolutely perfect accuracy or in which the slightest deviation would

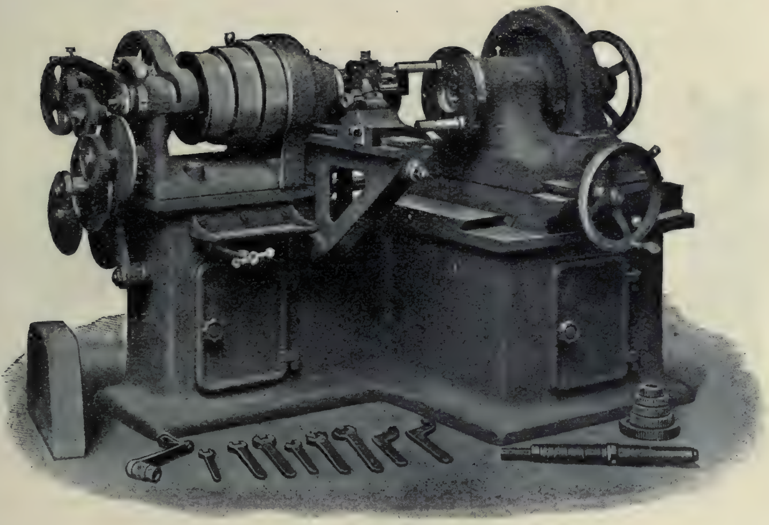


Fig. 322. Rotary milling machine.

not be permissible; on the other hand the machine will mill workpieces sufficiently well for a large number of purposes, so that with the exception of workpieces demanding perfect accuracy, there is still a wide range of usefulness for the rotary miller.

Figs. 323—327 illustrate various classes of work carried out on the rotary miller together with the cutters used in connection therewith.

Fig. 325 shows a handwheel, the semicircular circumference of which has been milled. In fig. 323 is illustrated a blank for a lathe change wheel, a mitre wheel will be turned out of the blank shown in fig. 326. Fig. 327 shows the muffler of a friction clutch: fig. 324 a small rope pulley. Not only small rope pulleys however, but even those varying in diameter from 24—36 ft. are nowadays milled on their circumference by the milling cutter.

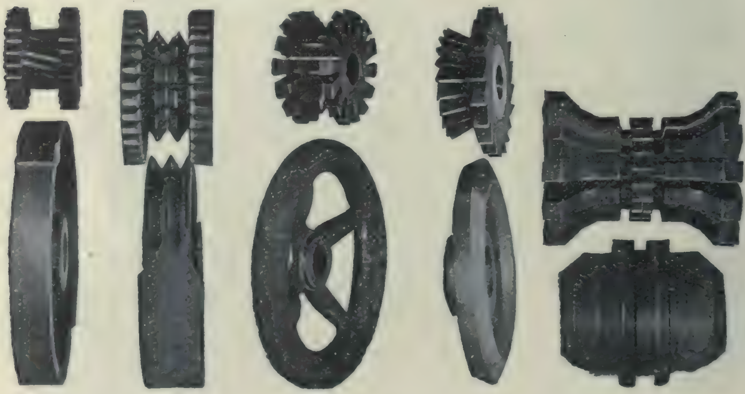


Fig. 323—327. Cutters and workpieces of the rotary milling machine.

The rotary miller has two principal motions, viz:—the rotary movement of the cutter and the slow rotary feed of the workpiece, both of which are actuated by the 3-step pulley 1. (Fig. 328).

The main drive is imparted to the three step cone pulley 1 by a cone pulley of similar dimensions on the countershaft. Pulley 1 is connected with wheel 2 and runs idle on the main spindle 3. Wheel 2 meshes wheel 4, which is mounted on a sleeve running idle on the shaft 9; at the left hand side this sleeve is formed as a clutch, which can be engaged with the clutch of gear 6 whenever the machine is set in motion.

Wheel 6 drives not only the main spindle but also the feed mechanism of the workpiece, since wheel 6 meshes not only wheel 7 which is keyed to the main spindle, but also drives shaft 9 at the same time by means of the spring key 8, from the right-hand extremity of which shaft the feed is derived by means of gear wheels. (Fig. 328).

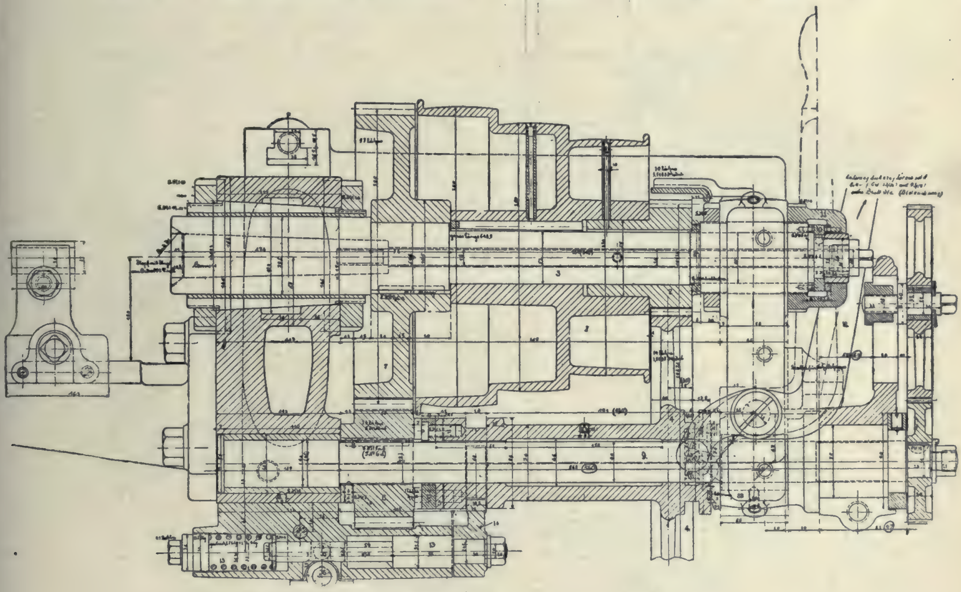


Fig. 328. Section over main spindle and back gears.

The main spindle runs in cylindrical bearings, the front bearing being adjustable. The spindle is bored to receive a rod by means of which the arbor cone is drawn tight in the spindle or forced out. The spindle nose is provided with a slot in which two notches fit on the cone of the arbor in order to prevent the cone of the latter from slipping in the taper bore of the spindle and so becoming damaged.

The lever 12, (fig. 328), reaching from the rear bearing of the machine to the place where the operator stands, permits of wheel 4 being shifted on shaft 9 so as to be engaged with wheel 6, thus setting the machine in motion. By moving wheel 4, the spring bolt 13 is also moved by the fork 14 which is forced by the hub of wheel 4, the spring behind the bolt 13 being compressed. Spring 15, being compressed, will have a tendency to release which would cause the machine to stop, but this is prevented by the hook lever 16, the hook of which engages a slot on the underside of the bolt. Figs. 329—331 show the mechanism.

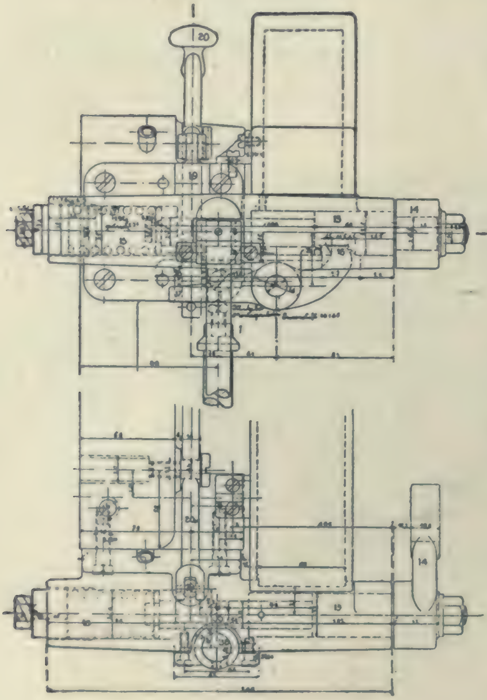


Fig. 329—330.
Mechanism for starting and stopping machine.

The left-hand extremity 17 of the hook lever 16, which is forced down by the spring 18, is connected with the long lever 20, by means of the bolt 19, the handle or lever 20 reaching over the front bearing of the machine to where the operator stands. To stop the milling cutter by hand, it is only necessary to press the knob of lever 20 when the connecting bolt 19 is lifted and disconnects lever 16 from the slot in bolt 13, as a result of which spring 15 is released and moves wheel 4; a leather thrust 21, (fig. 328), reduces the shock between wheel 4 and bearing 22.

The automatic stop of the machine is accomplished by means of the feed shaft 23 at the rear of the machine, (fig. 332), driven by the previously mentioned shaft 9, (fig. 328), by the gears 24, 25 and 26 and the friction

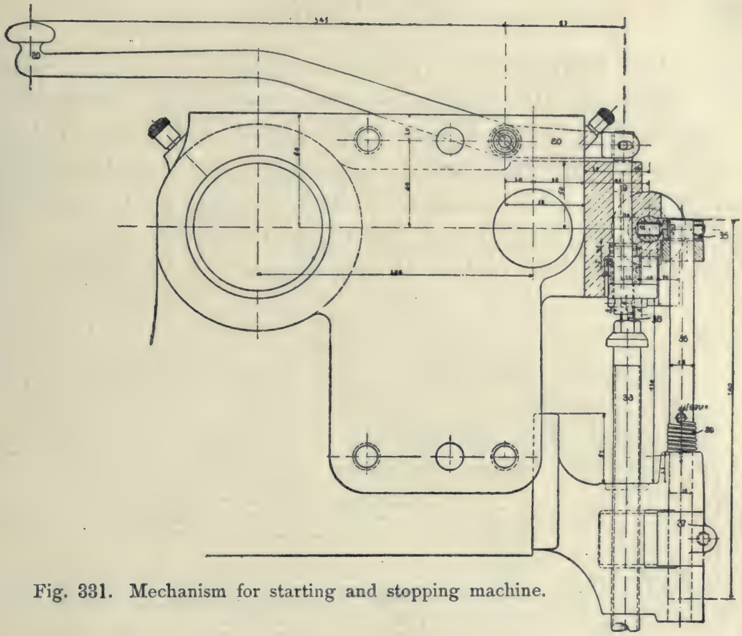


Fig. 331. Mechanism for starting and stopping machine.

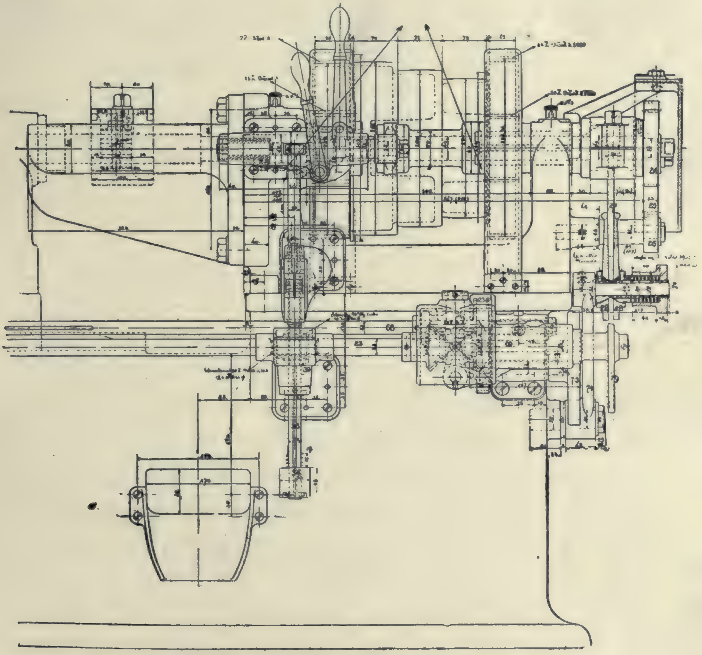


Fig. 332. Back-view of rotary milling machine.

discs 27, 28 and 29. In the housing 30, (fig. 333), shaft 23 drives the worm and worm wheel 30/31 as also the spindle 33, to the lower end of which is attached a weight 34, the upper end being threaded. As already stated, when the machine is started, bolt 13, (fig. 328), is shifted to the left which causes the vertical bolt 36 to engage a slot in bolt 13, which is just turned round far enough

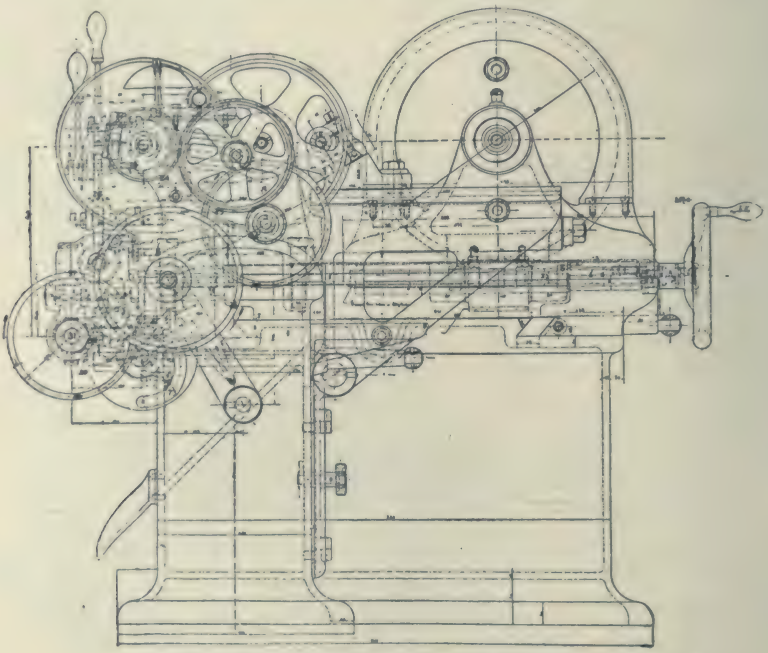


Fig. 333. Side-view of rotary milling machine.

by the small lever 35, (figs. 329—331), to permit of the cam block 37 engaging the thread of bolt 33. This bolt will at once rise owing to its being driven by wormwheel 32. At its top is placed an adjustable screw 38 which is forced by the bolt against the underside of the hook lever 16/17 and releases the hook from the slot in bolt 13, thus releasing the spring of bolt 13 and by moving this spring to the right, stops the cutter and the feed. The vertical bolt 36 is then turned by the lever

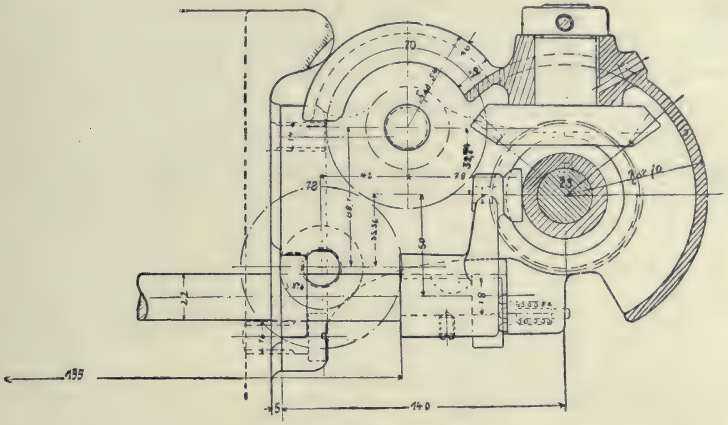


Fig. 334.

35 and the spring 39; the small block 37 is released from the thread of bolt 33 and the weight 34 draws the bolt down to its original position.

The automatic stop takes place each time the workpiece has completed a full turn. The starting point can be determined by the operator according to the requirements of each particular case, which is necessary since when another workpiece has been put on the machine, it must be fed in slowly to the rotating cutter by means of the hand-

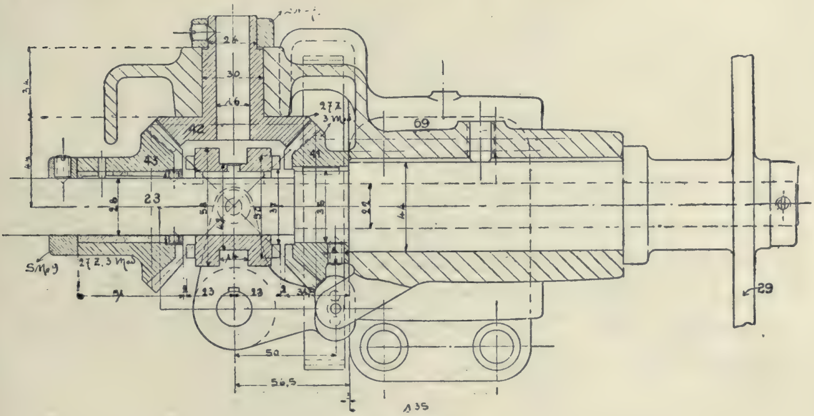


Fig. 335.

wheel 40 until the carriage strikes against the stop block. Only then is the desired diameter to which the workpiece must be milled, attained. During this handfeed, screw 33 is already raised so that the machine would be stopped too soon and a portion of the circumference of the workpiece would not be milled to the required diameter. To prevent this, directly the cutter has been properly adjusted, the operator taps knob 20 which stops the rotation of the workpiece for a moment, screw 33 falls back and lever 12 stops the rotation of the workpiece. Screw 33 starts for a complete turn of the workpiece, the machine being stopped exactly after a full turn.

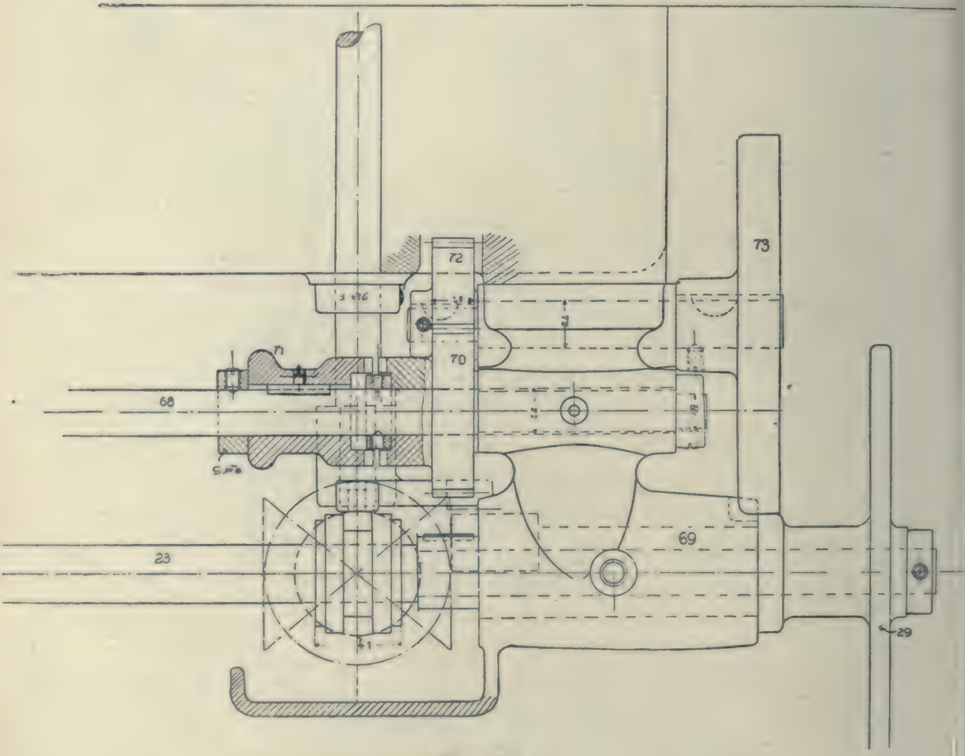


Fig. 336.

The feed of the workpiece.

The feedshaft 23 at the rear of the machine has its motion imparted to it by the lower friction disc 29, (figs. 334—336), as well as by the bevel gears 41—43, which are provided on account of the difference of circumference feed required for internal and external milling and can be engaged by the lever 44 at the front of the machine. The other end of the splined shaft 23 terminates in the box 45 and by means of the worm and wormwheel 46/47, (figs. 337—340), imparts motion to the shaft 48 in carriage 49, (figs. 341—342). The feed motion is transmitted to wormwheel 51 from shaft 48 by a second

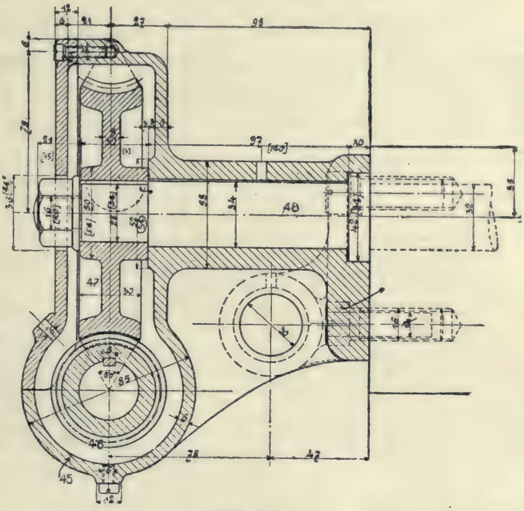


Fig. 337.

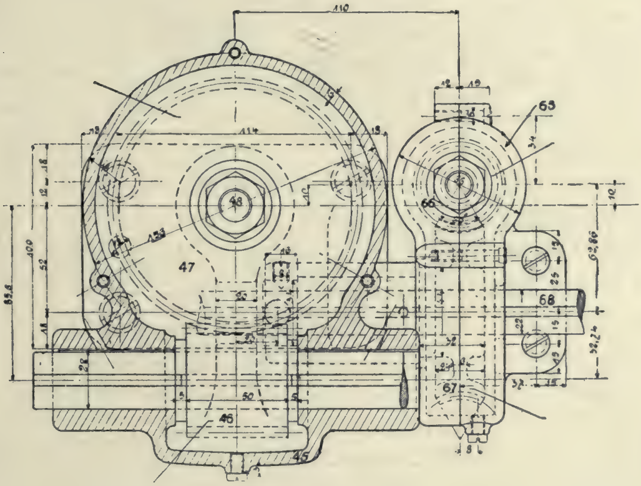


Fig. 338.

worm 50 and by the flange 52 to spindle 53. To adjust the workpiece by means of the handwheel 54, the flange and the wormwheel can be disengaged by unscrewing the four nuts 55. The square 57 is employed for the feed of the carriage 49 together with the workpiece in the direction of the cutter arbor. The workpiece is moved by handwheel 58 and spindle 59. Both carriages can be tightened by means of clamps. Stop 60 is used for external milling. As can be seen from fig. 342, this can also be adjusted by means of the square 61.

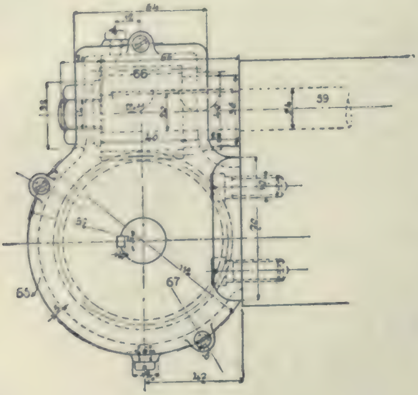


Fig. 339.

For internal milling two additional stops are introduced; stop 62 with nut and lock nut for feeding the workpiece square on the spindle and stop 63 on the front of the bed for feeding parallel to the cutter spindle, which is bolted in the ⊤ slot 64 and against which a button of the carriage strikes.

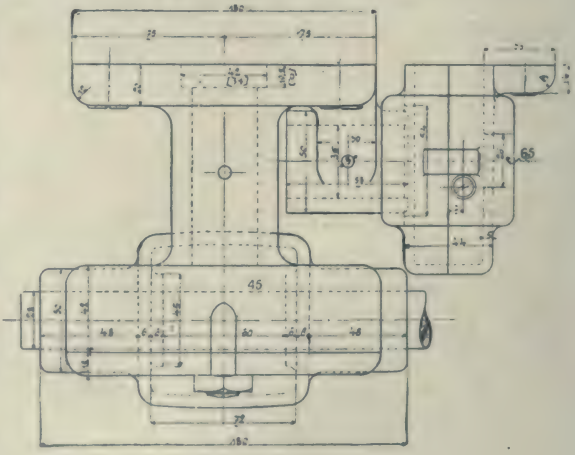


Fig. 340.

The rate of feed of the workpiece is so arranged that the feed remains practically the same for various diameters with the same gears. This is obtained in the following manner:

A worm in box 65 at the end of spindle 59 in carriage 49 meshing in wormwheel 67 (fig. 342) drives shaft 68 which is provided with a keyway and is carried at the other end in 69 where it drives the gear 70 and the clutch 71, whence motion is transmitted by means of gear 72 and friction disc 70. This shaft has thus a fixed ratio of

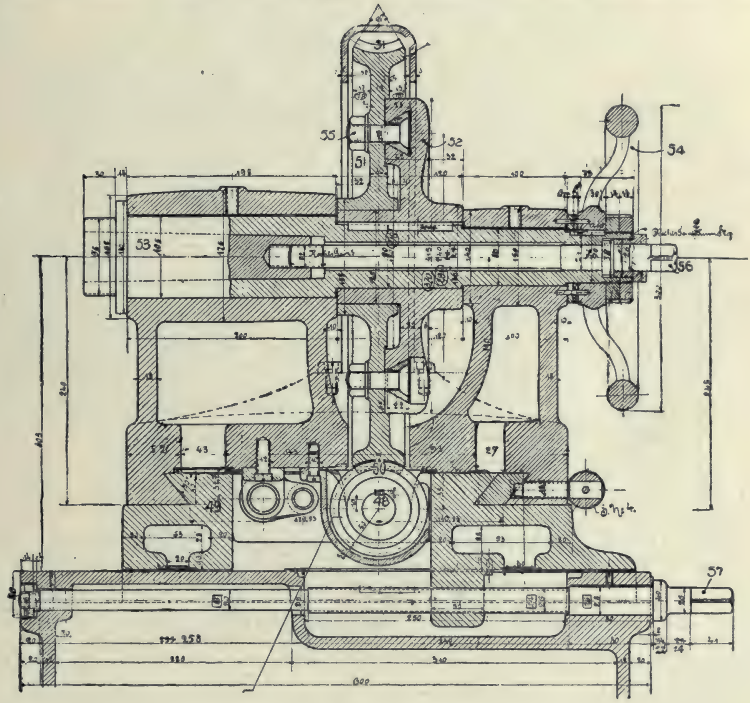


Fig. 341.

speed with the spindle 59 and rotates as soon as the workpiece approaches the cutter or retires from it. As the circumference of 73 is provided with a spiral groove in which runs a pin from the lever 74, the centre friction disc being attached to this lever, the lever 74 with the centre friction disc 28 is pushed either forwards or backwards by the feed of the workpiece. In this manner the position of friction disc 28 as regards the two others is changed, thus bringing about a change in the feed.

A small face plate 75 is mounted on the spindle for milling workpieces with a bottom or with spokes, the carriers of which drive the workpiece and consequently carry it along with it.

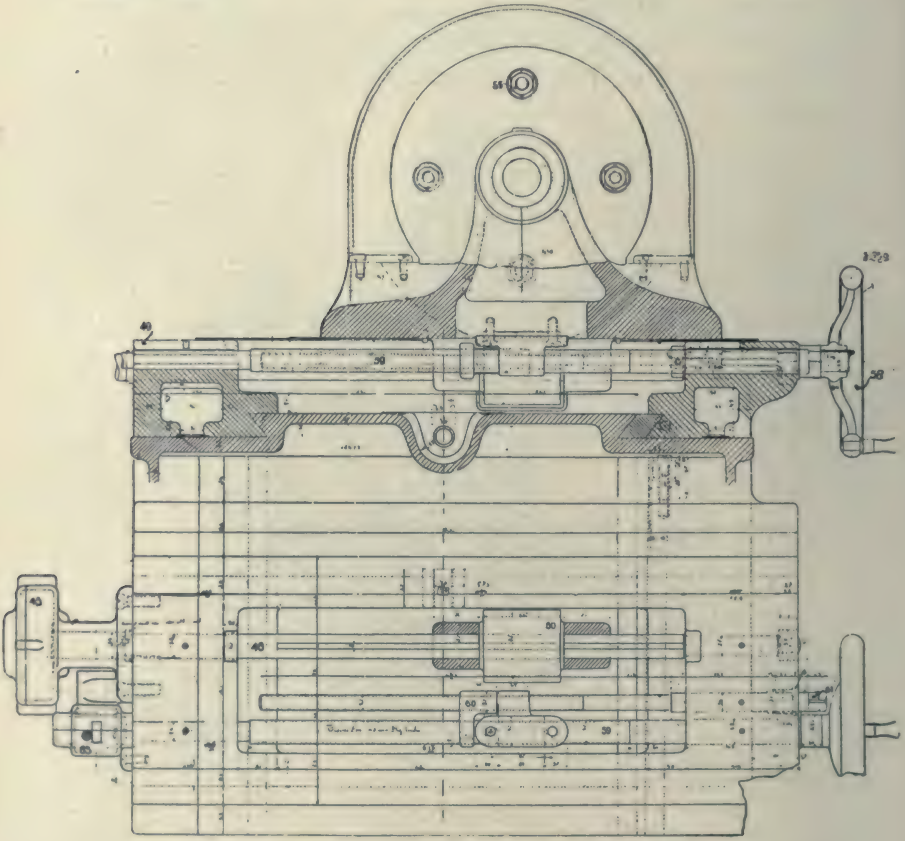


Fig. 342.

(*c*). THREAD MILLING MACHINES.

The thread milling machine being a rotary miller of special type, work can also be carried out on it which was formerly done on the lathe. Fig. 343 illustrates such a machine as built by Pratt and Whitney. It is built in various sizes suitable for milling different diameters and lengths.

Practically every type of thread can be milled with the single exception of a real square thread. A variety of types of threads which can be turned out on these machines are illustrated in fig. 344.

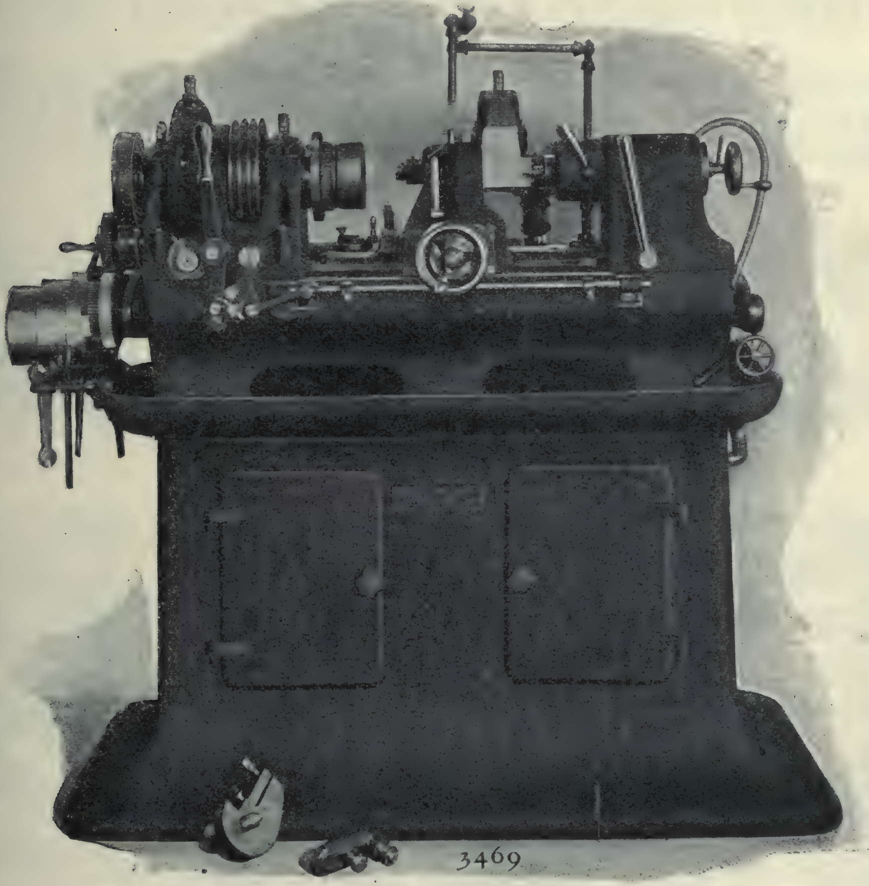


Fig. 343. Thread milling machine.

The machine itself is mounted on a box bed and pan. (Fig. 343). The maximum diameter and length which can be handled between centers is 6″ × 132″, but as the headstock spindle is hollow and the tailstock spindle can be

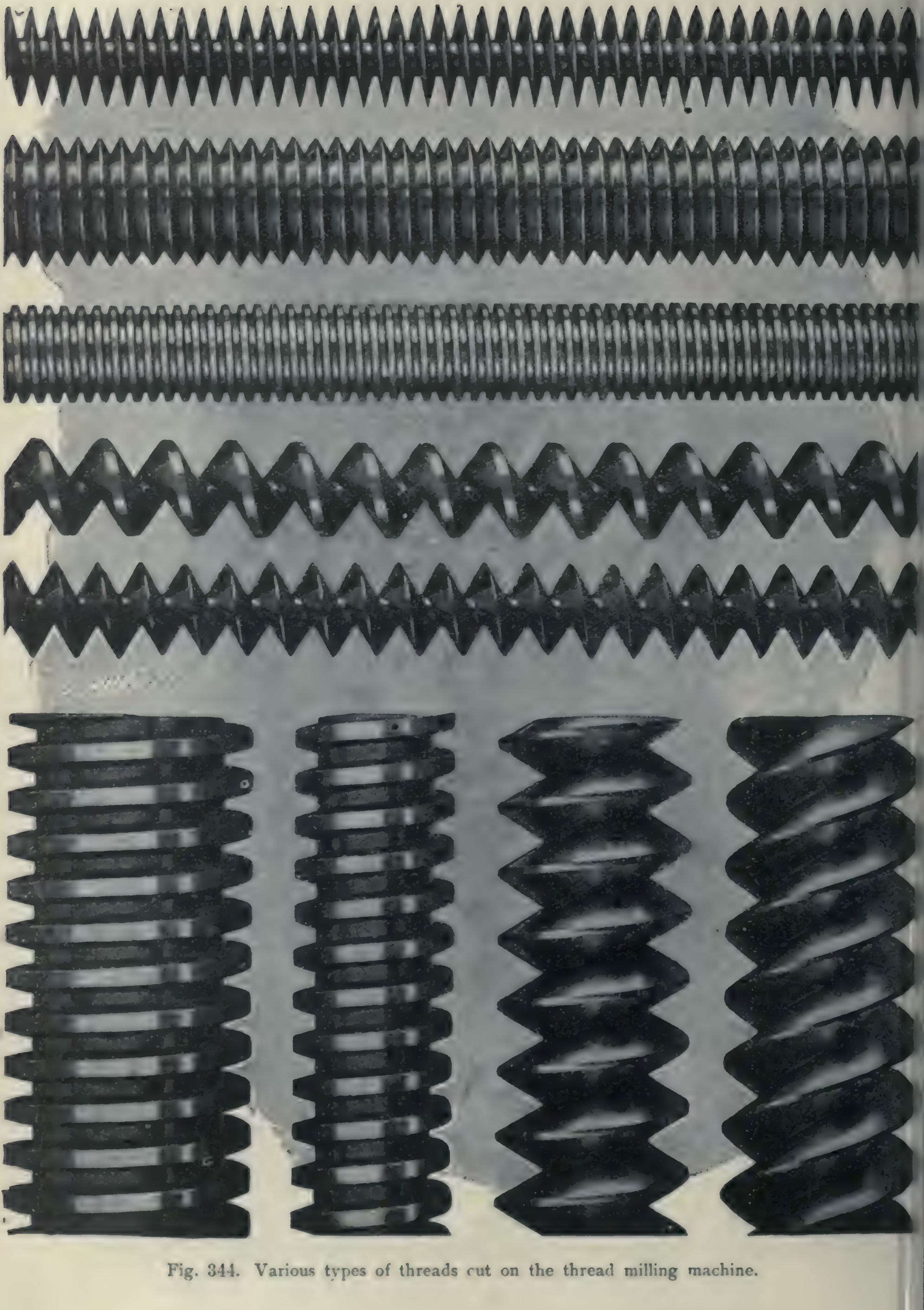


Fig. 344. Various types of threads cut on the thread milling machine.

removed the workpiece can pass through both and seeing that the thread can be picked up with perfect accuracy, the length which can be milled is practically limitless.

On the rear of the bed, the headstock and tailstock are carried on a single V and along a flat track at the front of the bed. The carriage rests on both sides of the bed on flat tracks, and is gibbed in a narrow angular slide at the rear. The lead screw J is in the centre of the angular slide. The cutter arbor is mounted in the head T connected to the cross slide L on the carriage K by trunnions which allow it to be tilted to any required angle for a given pitch of thread. The construction is such that at whatever angle the cutter may be set with T, the point of the cutter is always level with the centre line of the work. By means of a micrometer head S on the cross-slide screw, the depth of cut can be regulated for any given thread. An adjustable stop connected with the micrometer head S is provided for fixing the cut at precisely the same depth for repetition work. The blank being finished to size for outside of required screw, it is placed in the machine, the cutter being brought forward by the cross-slide screw till one tooth of the cutter just touches the external diameter of the blank, and the micrometer is then set at zero. The carriage with the cutter is moved along the bed to the end of the work and the cutter set at the required depth as indicated by the micrometer, in which position the cross-slide is then clamped. Then the proper change gears are placed for the required lead, the stop N^1 being set at the required point to knock-off the feed when the desired length of thread has been cut. The machine is then ready for operation and requires no further attention till the requisite length of thread has been cut.

The carriage K can be moved over the entire length of the bed independently of the change gears by turning the small handle P at the back of the carriage which revolves the lead screw nut through a worm gear. It is thus a simple matter to set the cutter at any desired point to begin the thread or to set a new cutter in its proper place whenever the necessity arises to replace the cutter in use for a new one. When the carriage is properly located, the lead-screw nut is locked in position by binding the worm, thus ensuring direct connection between the lead screw and carriage so that the carriage can then only be moved by the lead screw.

The lead screw has a $^1/_2$ inch pitch whilst change gears are provided for cutting threads from 12 per inch up to a thread of 15 inch pitch. The method of calculating the change gears is similar to that for lathe screw cutting.

The travel of the carriage is controlled by a lever M at the front of the head stock. When this lever is in its central position, i. e. vertical, the feed is tripped. If the lever be pushed over to the left-hand side, the feed is thrown in and when to the right-hand side, the carriage is returned; in the latter case the main spindle is driven by the rope pulley G, thus giving a relative fast speed. During the cutting operation this pulley remains idle on the spindle.

When cutting coarse threads of 1 inch pitch and upward, the carriage must be returned by hand; for this purpose the lead screw is provided with a square on which a handle can be mounted.

For cutting threads of 2 inch pitch and upward it is preferable to drive directly on the lead screw. This change is obtained by slacking the capstan-screw in the link O^3, allowing the link to swing downward till it locks the lower end of the lever M, thus locking the spindle clutch in its central position. The lead screw clutch can now be engaged by pushing in the knob on the front side of the head after the knock-off rod has been drawn to the right as far as it will go.

For cutting left-hand threads, it is necessary to reverse the direction of rotation not only of the cutter but also of the work and also to reverse the cutter on the spindle.

The cutter rotation is reversed by a clutch at the rear of the cutter head, that of the workpiece, (when driven direct from the spindle), by means of a clutch at the rear of the feed box. It is further necessary to place an idle gear in the train of change gears as the lead screw must rotate in the same direction whether right or left-handed threads are being cut.

Double, treble and multiple threads as also spiral gears can be cut on this machine by a very simple arrangement.

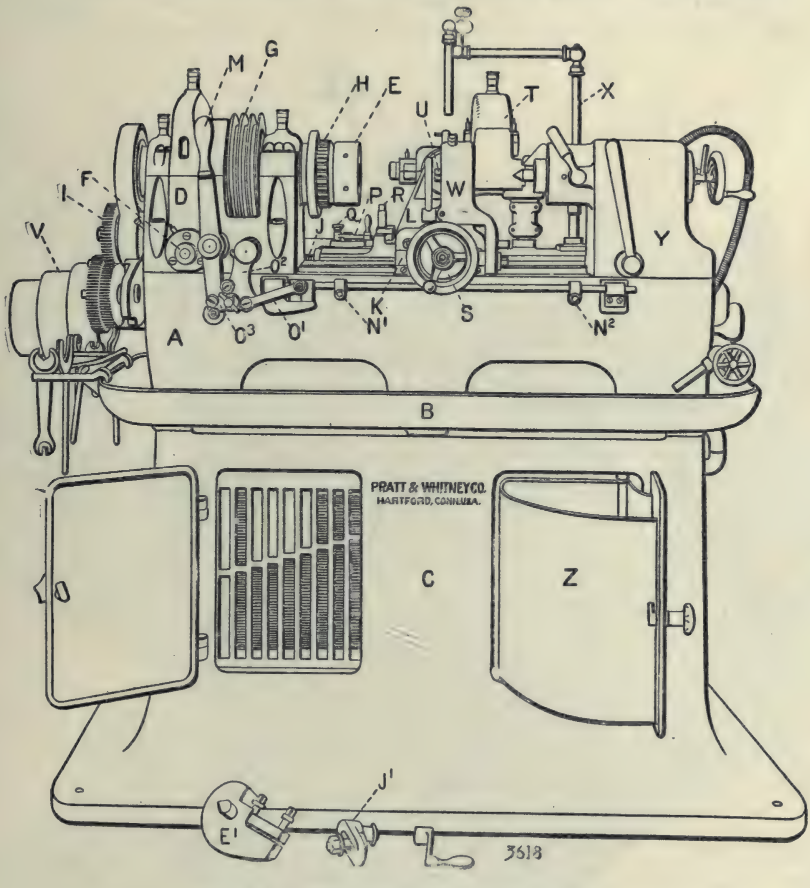


Fig. 345. Front view thread milling machine.

The spindle which carries the rope pulley and the spindle gear, is bored through its entire length and in this is placed an inner hollow spindle carrying the nose piece and collet. The inner spindle carries a notched index ring H, there being a pawl on the outer spindle, which locks the internal and external hollow spindles together. To index for a given thread, all that is necessary is to release the pawl from the notch it is in and to turn the inner hollow spindle that part of a revolution which is requisite to obtain the desired division. As the notched ring is divided, the exact

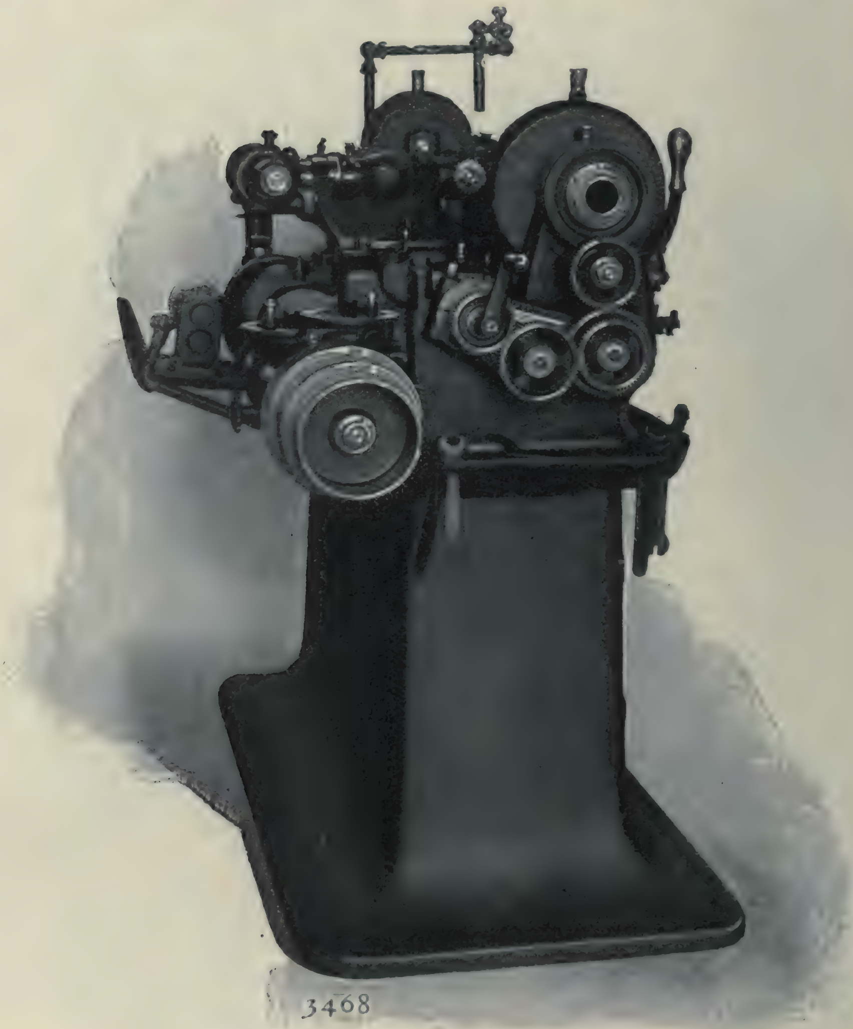


Fig. 346. Rear view of thread milling machine.

position can be accurately determined at once, after which the pawl is again engaged in its notch, thus once more connecting the two spindles. For a treble thread, for instance, a ring with 12 notches is employed, the spindle being turned over 4 notches. The divided ring supplied with the machine has 48 notches so that it can consequently be divided into 2, 3, 4, 6, 8, 12, 16, 24 and 48 parts.

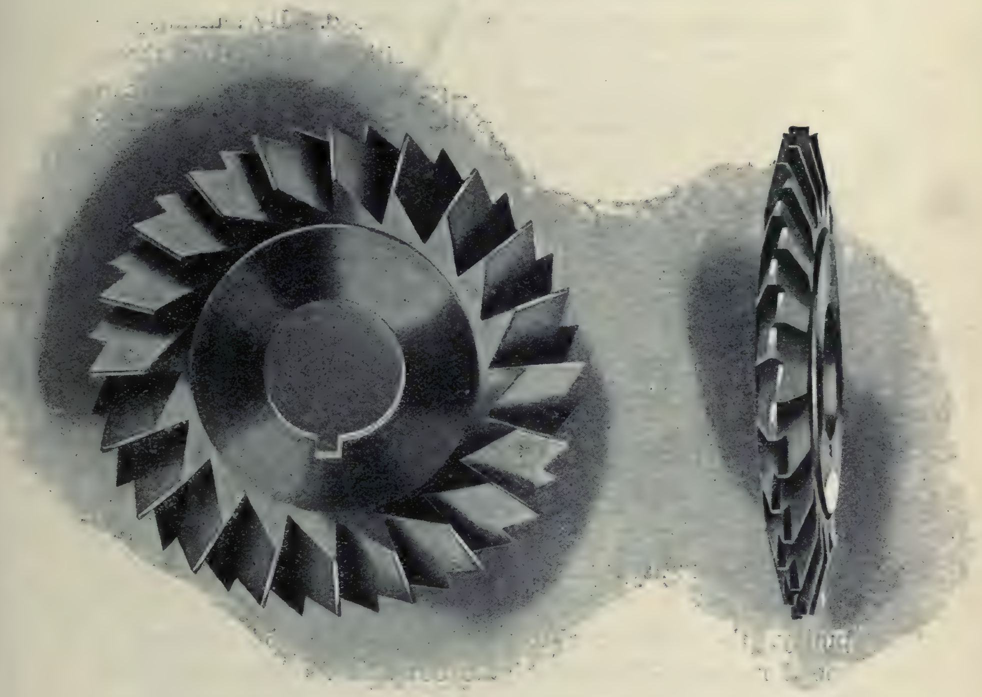


Fig. 347. Special cutters for thread milling.

The cutter head as also the feed is driven by a $2^1/_2$ inches belt. A three-step cone pulley is mounted on the end of the driving shaft, (fig. 345), which drives the main spindle by means of a number of gear wheels in the gear box in addition to driving the cutter head through the vertical telescopic shaft and bevel gears. Three different rates of speed can thus be imparted to the cutter by the cone pulley, suitable for different diameters of cutters and the varying quality of stock to be milled. The cutter drive is consequently direct so that it is impossible for the cutter to be damaged by the driving belt slipping. The oil pump is driven by a separate belt whilst the spindle is driven direct by the rope pulley for the quick return of the carriage.

The number of revolutions of the spindle can be varied by means of gears at the rear of the bed. By shifting two levers, one of which has six positions, the other three, eighteen changes of speed in geometrical progression can be obtained for each of the three speeds of the driving pulley, thus giving a total of $3 \times 18 = 54$ changes of speed not only for the spindle but also for the lead screw. By means of a reverse clutch these speeds can be engaged for left as well as for right-hand threads. The handles and mechanism can be seen in fig. 345 just above the cone pulley.

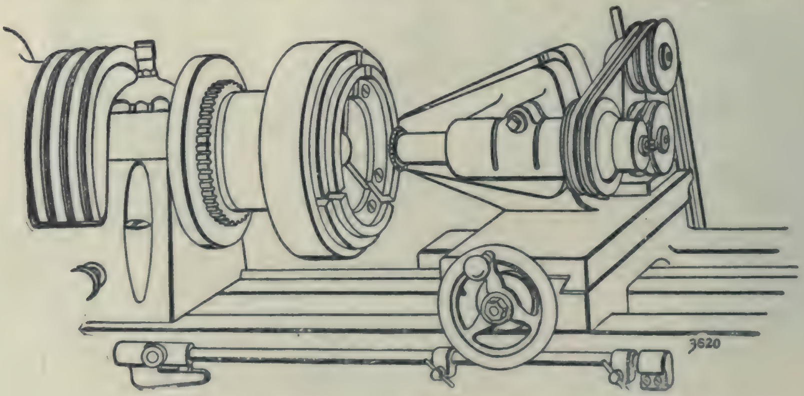


Fig. 348. Attachment for milling internal threads.

The cutters used on this machine are illustrated in fig. 347. The teeth of these cutters are staggered. Only one tooth cuts on both sides, the other teeth having but one cutting edge. For the accurate grinding of these cutters, a small special grinding machine has been constructed, which is indispensable to the machine.

Next to the point at which the cutter operates, the work-piece is supported by a rotating following rest arranged for interchangeable hardened and ground bushings corresponding to the diameter of the blank.

The machine can also be arranged for milling internal threads. In place of the customary cutter head, an attachment is mounted on the carriage specially for internal milling (fig. 348), a collet being mounted on the spindle nose corresponding to the diameter of the work to be milled, the machine is then ready for internal milling without any further change.

(*d*). GEAR CUTTING MACHINES.

The first gear wheels with cut teeth were turned out on the universal milling machine. The cutter was fed automatically through the blank, whilst each time the cutter had passed over the face, the table had to be returned by hand, the dividing head being shifted by hand before the milling of another tooth could be proceeded with. Although the actual cutting was thus automatic, that is to say, the machine required no continuous manipulation, gear cutting on the universal milling machine was not fully automatic.

Although some 40 years ago, machine tools were almost invariably supplied with cast teeth, now-a-day even machine tools of very indifferent quality are supplied with cut gears. On this account a lively demand has arisen, especially for machine tool manufacturing, for cut gears, as also for machines for producing cut gears cheaply and expeditiously and it was owing to this demand that the automatic gear cutting machine came into existence.

When speaking of automatic gear cutting machines, a distinction must be made between two entirely different types, viz:—those by which each tooth is milled seperately and is thus finished individually, and those by which the whole of the teeth are milled simultaneously according to the generating system.

The first type of machine is shown in fig. 349.

In practice, the manner of working is similar to that of the universal milling machine; the teeth are cut one at a time, the only difference being that the machine is fully automatic.

The manner of working is as follows;—After the blank has been placed on the machine and the proper change gears are mounted, the machine is set to work and feeds the cutter automatically through the metal; when the cutter has gone through, the slide with the cutter is returned automatically at an increased feed; when the cutter has returned to its starting point the gear blank turns over automatically one tooth further and the cutter is again fed through the metal. As soon, as the blank has completed a full revolution and all the teeth have consequently been cut, the machine is stopped automatically.

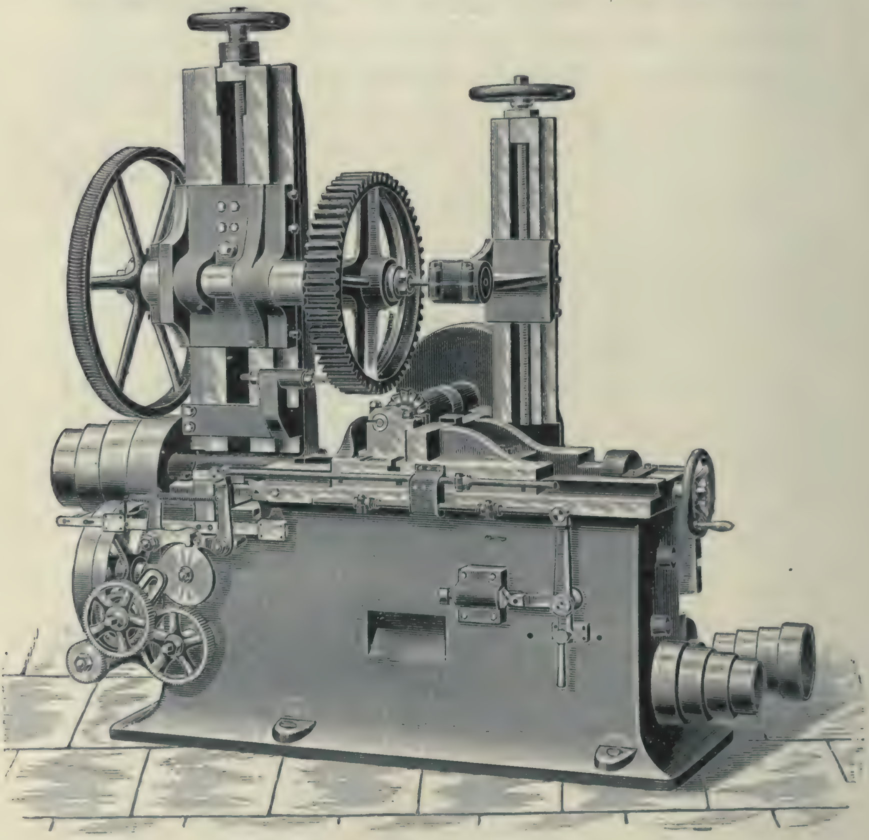


Fig. 349. Automatic gear cutting machine.

The main drive is obtained from the countershaft and a four-step cone pulley which drives the cutter arbor by means of a worm and wormwheel. The feed and return feed of the slide are derived from this shaft as also the movement of the blank.

To throw in the feed the lever in front of the bed is turned to the right. Connected to this lever is a horizontal rod provided with two adjustable dogs. These dogs can be adjusted according to the face of the blank to be milled.

A dog is also attached to the slide, which whenever it strikes against the dogs on the rod, shifts the rod with the lever, thus reversing the automatic movement of the slide, at the same time increasing the feed return three or fourfold. In order to prevent the lever from falling back, it is provided with a short cross arm, against which a plunger is forced by a spring; either the lower or the upper side of the slanting surfaces of the plunger is forced against the cross arm and keeps the lever in a fixed position unless it is forced over. When the dog on the slide has forced the lever over by striking against the dog on the rod and the slide has been returned to its original position at an increased feed, the blank is turned that part of a revolution required to obtain a certain number of teeth. The automatic dividing mechanism is shown in fig. 350.

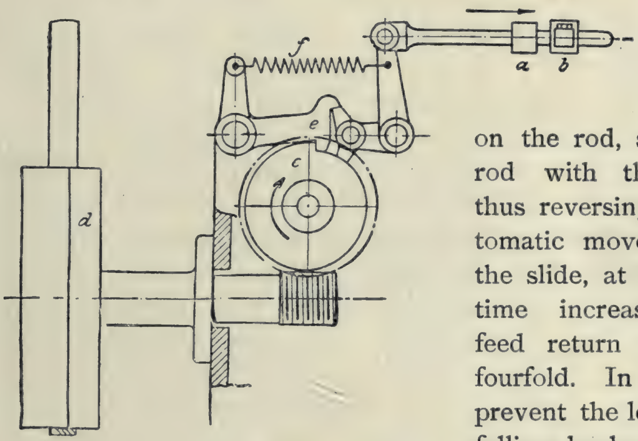


Fig. 350.
Dividing mechanism.

A wormwheel *c* is mounted on an intermediate shaft which makes a complete revolution each time for one division of the gear. For this purpose a fast pulley is mounted on the worm shaft next a loose pulley; on the fast pulley is a belt $^3/_4$ inch wide. This belt would drive the wormshaft and wormwheel if it were not that the pawl *e* prevents the worm wheel from rotating; before the worm wheel can rotate, or in other words, before the blank can be moved one tooth further on, the pawl must first be released, and this is effected by the cutter-slide.

The dog a strikes against the adjustable dog *b* on the upper rod carrying it with it a certain length; by means of a lever the pawl is lifted which, releasing the notched disc, prevents the rotation of the worm wheel; at the same time, the rod draws the belt from the loose to the fast pulley, which causes the blank to partly rotate by means of the gear wheels in the front of the bed.

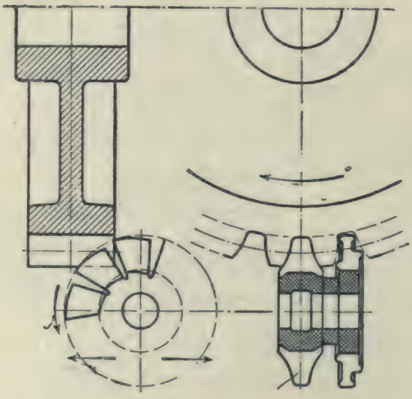


Fig. 351.
Roughing and finishing cutters working simultaneously.

Simultaneously with the gear wheels, the pawldisc turns and when this has completed a full revolution, the lever which holds up the pawl falls and thereby the pawl falls in the notch and the rotary movement of the gear wheel is thus strictly limited; at the same time the belt is shifted over to the loose pulley.

By changing the ratio of the change gears the blank can be turned such part of a revolution as there are teeth to be milled.

The teeth are milled from the full material. If, as formerly, the teeth were cast, then, (1) the cost of milling the teeth would be higher; (2) the turning of the rim would be dearer; (3) after having cut a few teeth, the cutter would be dull owing to its having to cut through the hard crust. For coarse pitched teeth however too much metal would have to be cut away to permit of this being done in one cut, so that the cutter would have to do it in two cuts; to avoid this, a preliminary cutter is placed by the side of the cutter which roughs out the tooth space (fig. 351), with the result that the finishing cutter has to cut away considerably less metal so that by this means even teeth of fairly coarse pitch can be milled in one operation.

Although this type of machine works fully automatically and turns out first-class work, it still has one great objection, viz:—for each pitch and for each size of gear wheel another cutter is required, which necessitates keeping a large stock of cutters on hand.

The custom has been universally adopted of using a set of cutters, (consisting of either a set of eight or fifteen), for gears of 12 teeth and upwards to the rack. For gears requiring accurary, the set of 15 is used; should perfect accuracy not be absolutely requisite, the set of 8 will be found to be sufficient. Should a cutter be desired with which an *absolutely* true tooth can be cut, it must be specially made to the exact circular and liniar pitch, since it is evident that a cutter which will cut a true tooth on a gear with 35 teeth could not possibly cut a true tooth on a gear with 41 teeth. Cutters in sets of 8 or 15 are on the market; if, however, a cutter is required for a certain definite number of teeth, it must be specially made.

The cutters of the set of 8 are used consecutively as follows:—

No. 8 for gears with 12—13 teeth
„ 7 „ „ „ 13—16 „
„ 6 „ „ „ 17—20 „
„ 5 „ „ „ 21—25 „
„ 4 „ „ „ 26—34 „
„ 3 „ „ „ 35—54 „
„ 2 „ „ „ 55—134 „
„ 1 „ „ „ 135— rack.

The set of 15 are employed af follows:—

No.	8	for	gears	with	12	teeth
,,	7½	,,	,,	,,	13	,,
,,	7	,,	,,	,,	14	,,
,,	6½	,,	,,	,,	15—16	,,
,,	6	,,	,,	,,	17—18	,,
,,	5½	,,	,,	,,	19—20	,,
,,	5	,,	,,	,,	21—22	,,
,,	4½	,,	,,	,,	23—25	,,
,,	4	,,	,,	,,	26—29	,,
,,	3½	,,	,,	,,	30—34	,,
,,	3	,,	,,	,,	35—41	,,
,,	2½	,,	,,	,,	42—54	,,
,,	2	,,	,,	,,	55—79	,,
,,	1½	,,	,,	,,	80—134	,,
,,	1	,,	,,	,,	134— rack.	

(*e*). GEAR HOBBING MACHINES.

The type of gear cutting machine previously described has this great advantage over the hobbing machine that it permits of the cutting of epicycloidal and other forms of teeth, whereas the hobbing machine only allows of the milling of evolute gears.

One of the first requisites for a smooth running gear wheel is that the arch of the teeth should be perfectly accurate. The epicycloidal form of tooth is fast going out of use owing to the cost of production being too high. For the milling of accurate teeth, it is a matter of the utmost importance that the cutter used for the purpose should also be perfectly true; but it is not sufficient that the cutter should have an accurate form, the relative position of the cutter must also be perfectly accurate as regards the centre of the gear. Even then it is not certain that an accurate gear wheel will be cut. The cutter must further be accurately adjusted on the milling machine relative to the position of the blank. Very primitive means are usually adopted for the cutter adjustment and the position of the blank, the adjustment of the cutter being generally guided by the eye alone. It goes without saying that it is impossible to cut an accurate gear in such a manner.

The milling of gears according to the hobbing process is accomplished under a totally different principle to that of the milling of the teeth one after the other with a gear cutter on a machine as shown in fig. 352.

The form and size of evolute-shaped racks are precisely the same for every circular pitch of gear whether large or small provided the pitch of teeth is the same; the form of the tooth being a symetrical trapezium, the sloping sides of which are at an angle of 30 degrees to one another.

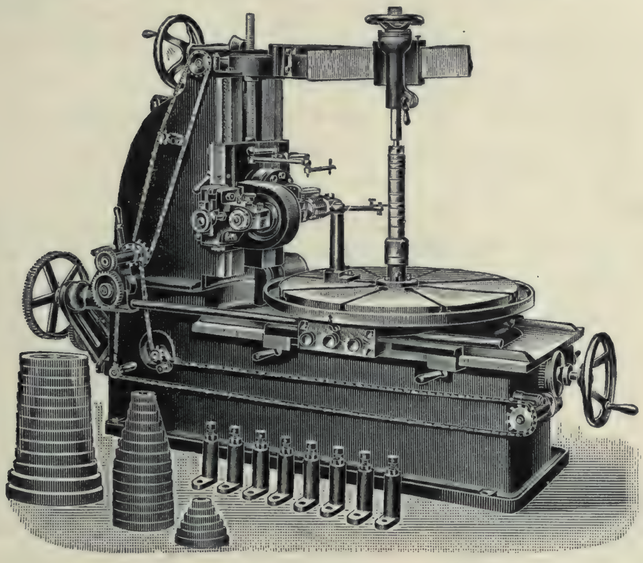


Fig. 352.
Gear hobbing machine. Position of gear blank on the machine horizontal.

In fig. 353 *a* is shown a rack, *b* being a gear of an arbitrary diameter and number of teeth. If *a* is moved slowly in the direction of the arrow 1, whilst *b* is revolved on its axis in the direction of arrow 2 in such a way that the circular pitch line 4-4 rolls upon the linear pitch line 3-3, the exact involute form of the imaginary gear will be obtained when all the metal between the teeth of the rack and the imaginary gear has been removed by the rack teeth; strictly speaking, it must be imagined that the teeth of the rack are somewhat deeper, the line of depth of the teeth of the gear somewhat filled up and vice-versa, so as to be equivalent to $^1/_6$ of the linear pitch (see fig. 353).

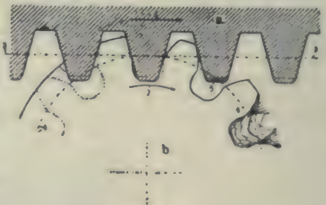


Fig. 353.
The principle of the hobbing system.

It is in along this principle that the gear hobbing machine works. In place of the rack which has no cutting capacity, a hobber works with relieved teeth as per fig. 354, the profile of its thread having the perfect form of the rack tooth but modified at addendum and the whole depth of line in the manner indicated above.

When cutting, the relative position of hob and blank is determined by the following conditions, (see figs. 355—357).

1. The pitch line of the hob is a tangent of the circular pitch line of the gear to be milled (see fig. 353).

2. The axis of the hob forms such an angle with the axis of the gear to be milled that the thread of the hob runs parallel to the axis of the gear wheel, (fig. 356).

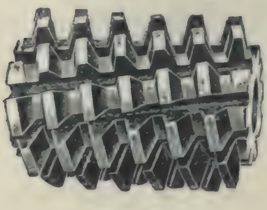
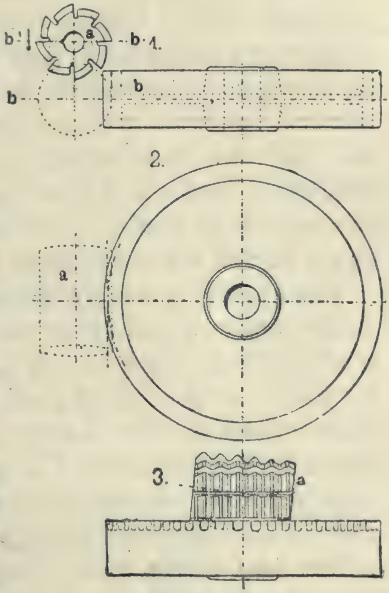


Fig. 354.
Gear hobber.

3. The pitch line of the hob touches the circular pitch line of the gear approximately in the middle of the face of the hob. Perfect accurary in this respect is not necessary. During the cutting process, the hob and gear rotate in fixed ratio in such a way that during one complete revolution of the gear, the hob makes as many revolutions as there are teeth to be milled. It must now be imagined that the hob is not in the position shown in fig. 355 but somewhat lower, in the position indicated by the arrow 1, so that a straight line *b-b* drawn through the centre *a* of the hob to the axis of the gear will bisect the latter. By the rotation of the hob other hob teeth come constantly in

the toothspaces and consequently more cutting profiles pass along this line. These teeth, which are similar in form, are in another position to the preceeding ones in the direction of the pitch line of the hob.

The distance traversed by one tooth of the hob during one revolution is equal to the pitch. It would thus appear as if the cutter profile moved over the tangent with the circular pitch line of the gear, whereas the latter rotates with a speed in accordance with the diameter and the number of teeth. It is evident that in this manner the toothform in the plane *b-b* is obtained in precisely the same way as that shown in the imaginary process in fig. 353 for the exact involute form of tooth. The hob, however, does not cut the tooth flank in an unbroken line since its teeth only cut when one of them passes over the surface. The flank of the tooth is consequently not formed by one single unbroken curve, but consists rather of a large number of straight surfaces forming together the evolute flank of the tooth and the greater the number of teeth, i. e. grooves the hob has, the more the total number of these small surfaces will approach the perfect evolute line. For this reason it is advisable to have as many grooves in the hob as possible. However, the surfaces composing the flanks of the teeth are so small that even with a hob with a small number of grooves, they are scarcely perceptible.



Figs. 355—357.
Relative position of hob and blank during process of milling.

For gear cutting according to this principle, two types of machines, differing widely one from the other, are employed.

In the first type, shown in fig. 352, the axis of the blank is vertical, in the other, shown in fig. 358, horizontal. In their general construction they also differ greatly from one another, though both work on the same principle.

The manner in which the machine illustrated in fig. 352 works is as follow:—

By means of bevel gears the cone pulley drives a vertical shaft in the interior of the vertical column, which shaft is provided with a keyway from which a bevel gear mounted on the sliding head is driven, the spindle being driven by another bevel gear which meshes that just referred to through a second set of bevel and spur gears. The spindle, the train of gears and the bevel gear that meshes the gear on the vertical spindle can, together with the swivelling part of the sliding head, be swiveled vertically in a complete circle, so that the spindle can be set at any angle in the vertical plane.

The change gears by means of which the table speed is determined are driven by the cone pulley shaft. The horizontal splined shaft at left hand side of the bed is driven, by means of a train of gears and carries a worm meshing a worm wheel almost as large as the diameter of the table to which it is connected. The consequent result is, that there is a fixed ratio between the table and hob speed which can be varied by the change gears.

The feed of the slide along the vertical column is derived from the horizontal shaft along the bed. A worm on the shaft meshes a worm wheel which in its turn drives a sprocket wheel by a train of gears which by a chain drives a sprocket wheel on top of the column; the worm of the shaft on which this sprocket wheels is mounted drives a worm wheel which is provided with a square thread and turns the vertical screw-spindle which moves to the slide up and down.

The worm on top of the vertical column can be disengaged either automatically or by hand at any desired point, whilst by two bevel gears which drive the worm wheel, the slide on the vertical column can be moved up and down by hand.

For gauging the exact depth of cut, a large dial with micrometer division is fixed on the feed screw of the table, so as to adjust the position of the table accurately.

As the form of the teeth of a rack are, given a certain pitch, the same for all gears, all gears of the same pitch can be cut with the same hob, and, since at the present day all gears have a pitch which contains the value π, only a comparatively small number of hobs are required.

In addition to spur gears, worm wheels can also be cut on these machines.

In the latter case, the slide is clamped on the column, the cutter arbor is level (since the teeth of the worm wheel are at precisely the same inclination as the thread on the hob), and the axis of the hob is adjusted exactly over the middle of the width of face of the worm wheel. From the same spindle which drives the vertical feed of the slide on the column, a chain drives a sprocket wheel in front of the bed keyed on a worm shaft meshing a worm wheel mounted on the table feed screw, the gear being fed horizontally to the hob. In other respects the manner of working is the same as for spur gears.

Not only spur and worm wheels but also spiral gears can be cut in this manner. The manufacture of spiral gears differs from that of spur gears in that the feed of the hob is no longer parallel to the axis of the blank but is in a spiral line over the face of the blank. The hob is the same as that used for cutting spur gears and worm wheels.

Certain practical difficulties stand in the way of getting the hob to follow a spiral line directly, but this can, however, be obtained indirectly as the result of the feed parallel with the axis and an increase of speed of the hob or gear during the revolution.

A spiral line is thus obtained by increasing the number of revolutions of the hob required for traversing the width of face for a certain number of teeth by for instance, one revolution, the number of revolutions of the blank remaining the same. The result of this additional revolution of the hob combined with the vertical feed is the spiral line of the teeth of the spiral gear to be manufactured.

The manner of working in the case of spiral gears is as follows:—

If a hob be employed with a single thread of $^3/_4$ inch pitch, the feed screw of the slide having a pitch of $^3/_{16}$ inch and a gear is to be cut with $^3/_4$ inch face and 30 teeth at an inclination of 45 degrees, then in the first place, a train of gears must be mounted which will cause the blank to complete one revolution against 30 revolutions of the hob.

In order to impart to the slide and hob a movement in a straight line of $^3/_4$ inch, the feed screw which has a pitch of $^3/_{16}$ inch, must complete four turns. At the same time, however, the hob must describe a spiral line of 45 degrees over the face of the blank. To obtain this, the four revolutions of the feed screw cause a compound movement of the hob by means of a train of gears in such a manner that the hob performs just one more revolution during these four turns than is necessary for the given number of teeth. This additional revolution is completed during the time that the hob gets a vertical feed of $^3/_4$ inch. The result of this compound movement is a spiral line with an inclination of 45 degrees.

In the foregoing example it has been taken for granted for the sake of simplicity that the number of revolutions of the hob as opposed to the number of revolutions of the blank requires to be increased by exactly one revolution.

It goes without saying that this will be only the case with an inclination of the teeth of 45 degrees, other angles requiring more or less increase of the hob speed according to a larger or smaller inclination of the teeth.

The same result can also be obtained by reducing the number of revolutions of the blank during the time that the slide is traversing a distance equal to the width of face of the tooth by one or more or a fraction of a revolution, so that the position of the hob to the blank being altered, spiral lines are obtained.

In this manner spiral gears with varying lead can be cut with one and the same hob according as the hob is forced to an increase of speed of one or more revolutions or the blank speed is slackened in the same manner.

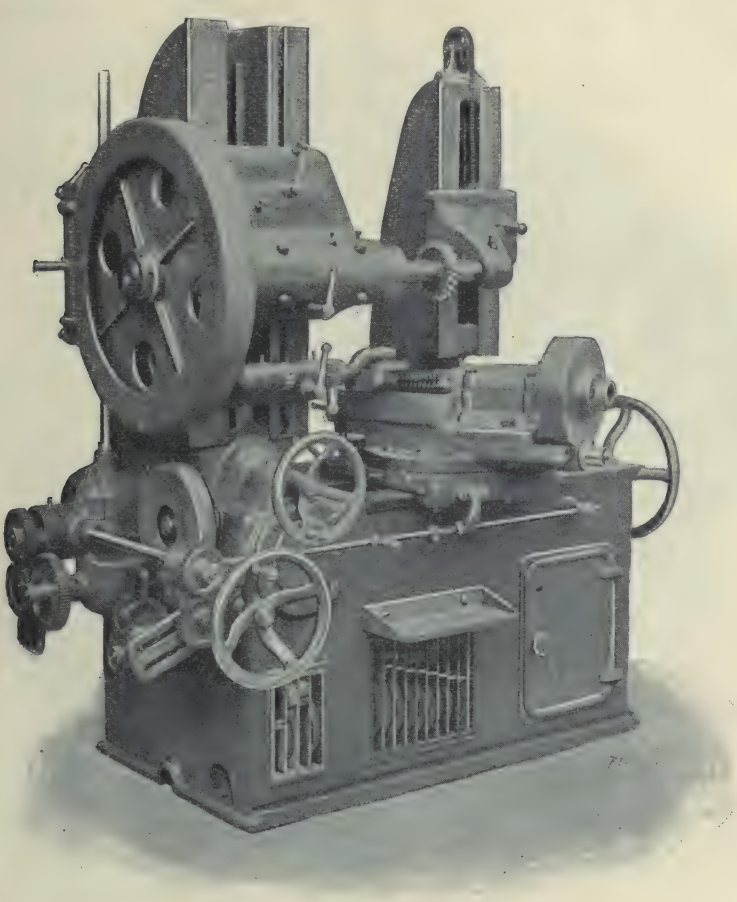


Fig. 358.
Automatic gear hobbing machine. Position of gear blank vertical.

In either case, however, the axis of the arbor on which the hob is mounted must be set at such an angle that the direction of the hob thread corresponds with the slope of the teeth of the gear.

Fig. 358 illustrates another type of gear hobbing machine. The slide on the vertical column is only vertically adjustable and cannot swivel. The blanks are mounted in a vertical position on an arbor carried on this slide and supported on a stay on the additional column. The hub is carried horizontally and rotates in the carriage on the bed which it traverses automatically. For the rest, what has already been said

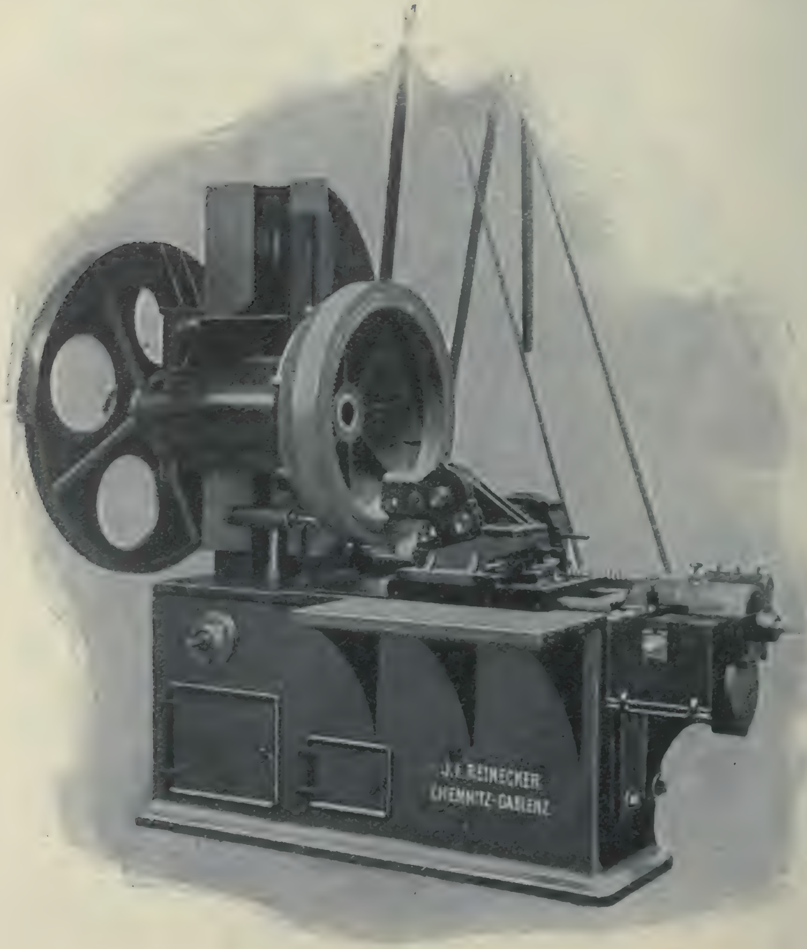


Fig. 359. Hobbing machine with attachment for cutting internal gears.

with reference to the machine shown in fig. 352, applies equally as well to this machine, thus rendering any further description superfluous.

Reinecker, who has put on the market a gear hobbing machine very similar to that illustrated in fig. 349, supplies an attachment to his machine for the cutting of internal gears as per fig. 359; from the nature of the construction, this attachment does not permit of so much material being cut away in one cut as is the case with an ordinary gear wheel with teeth on the peripheral.

Preliminary cutting is therefore necessary in the case of wrought iron, cast steel and suchlike tough materials as also for an anyway coarse pitch. This preliminary cutting can, however, be carried out at the same time, that is to say, a cutter which will cut out a large part of the tooth space can be mounted by the side of the gear cutter which cuts the true space of the teeth, so that the latter has to cut away but little metal. In this manner, internal coarse pitched gears can also be cut. If however, a perfectly accurate gear is desired, it is necessary to go over all the teeth with the finishing cutter once again, taking a very light cut.

Reinecker further makes a specialty of machines for cutting worm wheels and worms. With a hob as shown in fig. 354 worm wheels may be cut and, provided the pitch is not too coarse, they may be considered fairly accurate, (i. e. for all practical purposes), though the manner in which worm wheels are cut with a hob in such a way conceals a rather serious fault, which becomes so apparent in the case of worm wheels with a coarse pitch that it is no longer possible to cut such coarse pitched worm wheels with a hob of this kind.

The question is that the hob will only mesh in the worm wheel accurately when the pitch line of the hob tangents with the circular pitch line of the worm wheel. The diameter at the whole depth circle of gears is considerably smaller than at the addendum circle or outside diameter. The distance from axis of hob to axis of worm wheel with hob in accurate mesh is consequently smaller than with hob and worm wheel touching their outside diameters. The worm wheel however, is fed to the hob diametrically. The addendum line of the hob which is intended to rotate in the whole depth line of the worm wheel, starts cutting on the *outside diameter.* It is only when there is a fixed ratio between the number of revolutions of the hob and of the worm wheel blank, that a worm wheel with the desired number of teeth is obtainable. If the rotary movement of the worm wheel was only caused by motion of the threads of the hob, a totally different result would be obtained. This can easily be proved.

Fig. 360. Worm-wheel hobs.

Given that a worm wheel with 50 teeth, 5 pitch, is to be cut.

The diameter of the pitch circle is thus $50 : 5 = 10$ inch, the circular pitch being $\frac{10}{50} \times \pi = .6285$ inch.

Diameter of addendum circle being $\frac{52}{5} = 10.4$ inch.

The outside circumference is thus $10{,}4 \times \pi$ inches.

Dividing the circular pitch on the outside circumference (which is the case if the hob rolls freely along the outside circumference), $\frac{10{,}4}{0{,}2} = 52$ teeth mill be obtained instead of 50.

It is thus obvious that when commencing cutting on a worm wheel with a hob as illustrated in fig. 354, in addition to rolling upon each other the speed of the blank must also be increased $\frac{0.4'' \pi}{50}$ per tooth. In commencing cutting, the free rolling of hob and worm wheel blank upon each other is thus out of the question. The more the pitch line of the

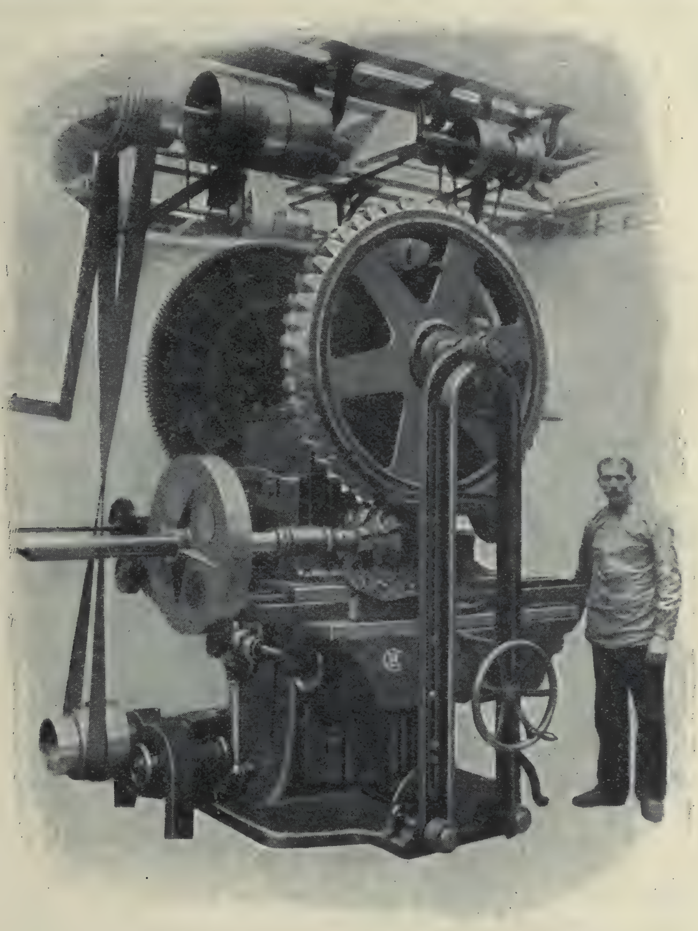


Fig. 361. Worm wheel hobbing machine.

hob approaches the pitch circle of the worm wheel blank by a diminution of the distance from its centres, the more freely the hob will roll, but the hob will only be perfectly in mesh when the pitch line and pitch circle actually coincide, i. e. when the worm wheel is finished, so that any error that has been made in the form of the teeth is irreparable.

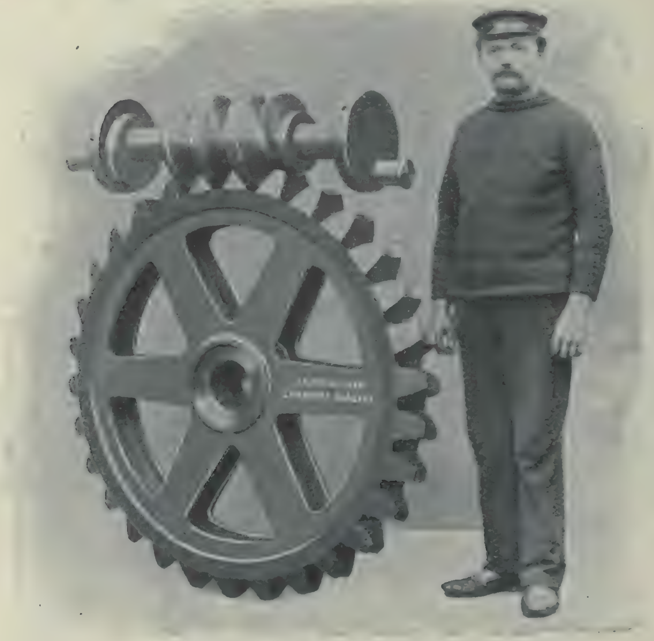


Fig. 362.
Worm and worm wheel. $\frac{10}{16}$ Pitch. Worm wheel with 30 teeth.
Diameter of pitch circle $30 : \frac{10}{16} = 48$ inches.

The foregoing example would be still more striking if a much coarser circular pitch were taken for the same pitch circle, whilst above a certain limit of ratio, between the circular pitch, the pitch circle and width of face, the cutting of a worm wheel with a hob as illustrated in fig. 354 would be an impossibility. Worm wheels cut in this way should have but little bearing on their toothflanks and are useless in cases where there is great pressure on the teeth.

The only true method of manufacturing worm wheels is to set the hob at once at the exact distance from the centre of the blank and feed it into the blank sideways.

Fig. 360 shows three of such hobs. The two outer ones with right and left-hand single thread have a pitch of $2^1/_4$ inches and a diameter of 12 inches, the centre one with right-hand single thread has a pitch of 5 inches and a diameter of 12 inches.

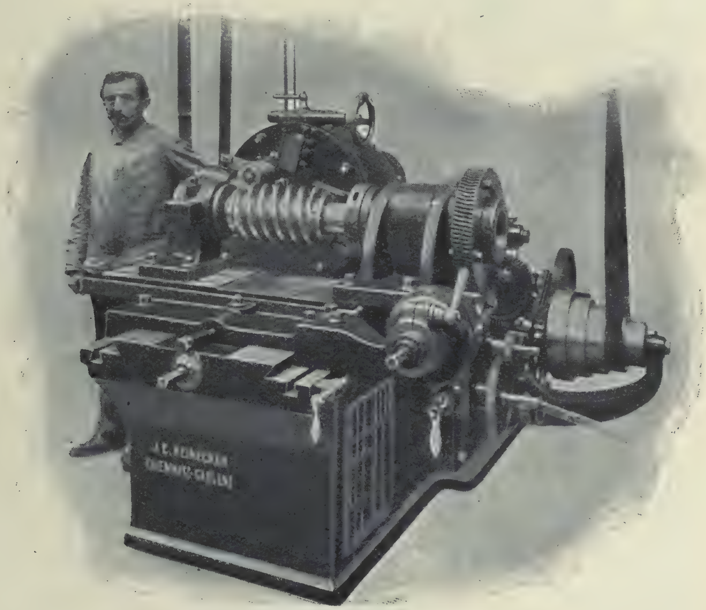


Fig. 363. Worm milling machine.

Fig. 361 illustrates a Reinecker worm wheel hobbing machine. At the commencement of the cutting operation the distance between the centre of the hob and the worm wheel blank is accurately adjusted, the hob being fed in with its small diameter on the blank and travelling completely through the worm wheel. In this way an accurately cut worm wheel is obtained.

The large dimensions to which worm wheels are manufactured at the present day are clearly shown in fig. 362 which depicts a 30-toothed worm wheel of $^{10}/_{16}$ pitch which was cut on one of Reinecker's machines in 26 hours.

Reinecker also builds automatic milling machines for milling worms of similar dimensions, as shown in fig. 363.

The carriage travels over the box-shaped bed along prisma bearings. The spindle rotates in housings in the swiveling head which can be set at any desired angle.

The dividing head spindle is bored over its entire length so that not only worms provided with a bore but also those which form part of a shaft can be milled on the machine. The feed of the carriage and workpiece is derived from change gears at the side of the box-shaped bed, the ratio between them being determined by the pitch of the worm.

The machine is driven by a five step cone pulley, motion being imparted to the carriage by worm and worm wheel.

(*f*). THE „WARREN" AUTOMATIC BEVEL GEAR GENERATING MACHINE.

Bevel gears cannot be accurately cut on the universal milling machine. If such be attempted through lack of a suitable machine, the accurary of the bevel gear will have to be sacrificed to the desire to get a gear with cut teeth to such an extent that a gear wheel with accurately cast teeth would even be preferable to such a gear with cut teeth.

For a long time the only means of obtaining a bevel gear with accurately machined teeth was by planing.

With the machine illustrated in fig. 364, which is constructed according to the *Warren* system, it is now possible to cut the teeth of bevel gears fully automatically and to turn out a perfectly accurate form of teeth on the milling machine. The system along which this machine works is as follows:—

Each of the wheels of a set of bevel gears can roll over a crown gear wheel in which the teeth lie flat in the circumference of a circle. The flanks of the teeth of a flat gear, however, approach a straight line to such an extent owing

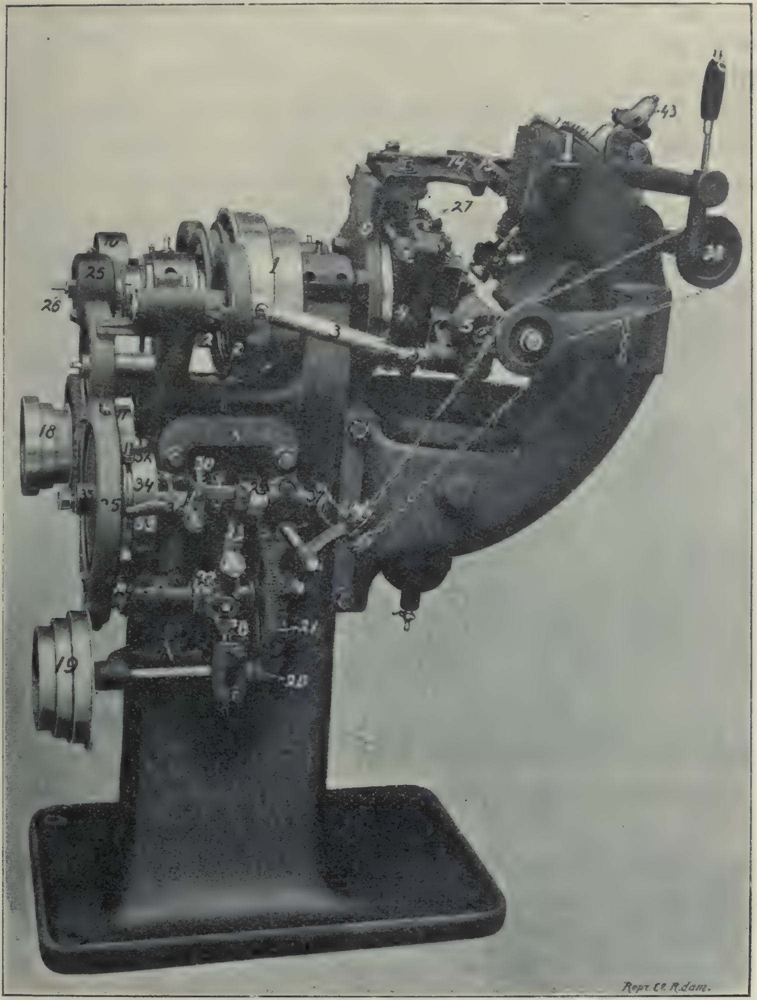


Fig. 364. Warren's bevel gear generating milling machine.

to the evolute form of the teeth, that in practice a cutter with straight flanks can be employed without any fear of committing any appreciable fault.

Supposing that a flat crown gear, the flanks of the teeth of which, as well as those of the rack, are straight lines, has been formed as a cutting tool, then the possibility is opened up that if this crown gear with cutting teeth rolls over another bevel gear wheel, a perfect bevel gear will result.

In Warren's machine, two cutters form two flanks of the teeth of an imaginary flat crown gear whilst all movements of the individual parts of the machine are arranged so as to obtain the same results as if a flat crown gear rolled over the bevel gear blank cutting away the superfluous metal.

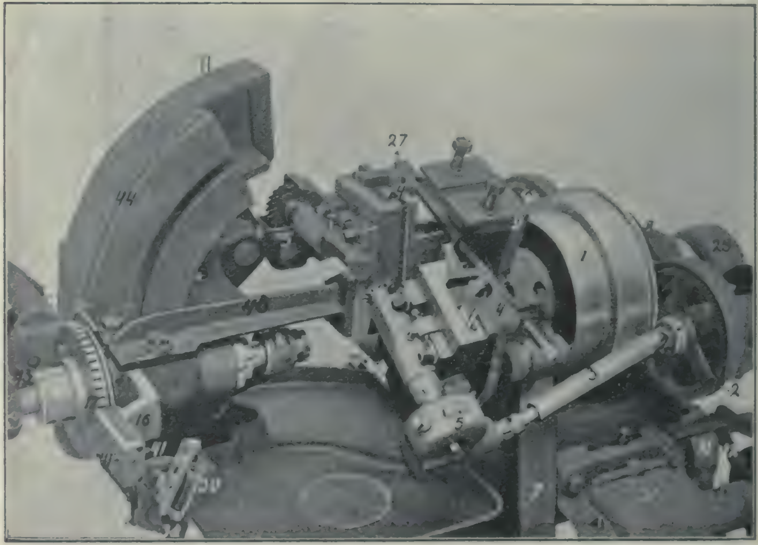


Fig. 365. Adjusting the rocker head according to diameter of bevel blank.

A rocking motion is imparted to the cutter, the total movement of which corresponds to the rolling of the flat crown gear over the bevel gear; the cutters revolve on their own axis, having, at the same time, an automatic up and down feed, the blank being turned over one tooth at the end of the return of the cutters.

The rotary motion is transmitted from the two-step cone pulley (fig. 364), to the two cutters by means of the gears 2, the universal jointed telescopic shaft 3 and a set of spiral gears in the box 5.

In contradiction to the usual practice on milling machines, the two cutters do not cut against the feed, but the direction of the rotary movement and that of the feed is the same so as to force the bevel gear blank by the pressure of the cut constantly against the shoulder of the arbor on which it is mounted, thus ensuring a perfectly accurate position.

The rocking motion of the cutters is imparted by the shear 6 and the link 7, (figs. 365, 367 and 368), the latter being attached to stud 8 of the large flange 9, from whence a rocking motion is given to the rocker head. The shear 6 acquires its movement from cone pulley 1, gear wheels 2, belt pulleys 10 and 11 and the gear wheels 12, (fig. 367).

The length of stroke of the link 7, as also the rocking of the head, can be changed in accordance with the teeth to be milled by adjusting the point of contact of the link on the shear. The adjustment is accomplished by means of the adjusting screw 13.

The to and fro motion of the cutters representing a part of the flat crown gear, is transmitted to the workpiece in fixed ratio by the tooth segments 14 and 15, (fig. 367). The angle of the bevel gear blank with the imaginary flat crown gear wheel consequently depends upon the ratio of the pitch circle of the flat gear and that of the bevel gear blank. The segments 14 and 15 are interchangeable. For each different set of bevel gears, two new segments are necessary.

In a larger size of machine these segments have been dispensed with. The rocking motion is then obtained by an adjustable shear which allows a ratio between the two bevel gears of 1 : 1 to 1 : 6.

Segment 15 is attached to arm 16 which swivels the index plate 17 and with it the spindle on which it is mounted, by means of a pawl which meshes the index plate.

The feed motion is transmitted by the three-stepcone pulleys 18 and 19 by the same shaft as that driven by gear 12 which imparts motion to the shear 6. The gears 20 and 21 transmit motion to clutch 22, (fig. 364). If the lever 23 has engaged the feed, (see fig. 364), the clutch 22 carries with it gear wheel 24, transmitting motion by the gears which run in the gear box 25 to shaft 26. This shaft is carried in the hollow main spindle. Spiral gears, carried in the rocking head 4, not visible in the illustrations, further transmit the feed motion from shaft 26 to the feed screws 27, which finally transmit feed motion to .the cutter slides. If the roll of lever 23 is on the right-hand side of the pin 28 immediately beneath it, and which is forced by a spring, the return clutch 29 is engaged, clutch 22 for the down feed being disengaged.

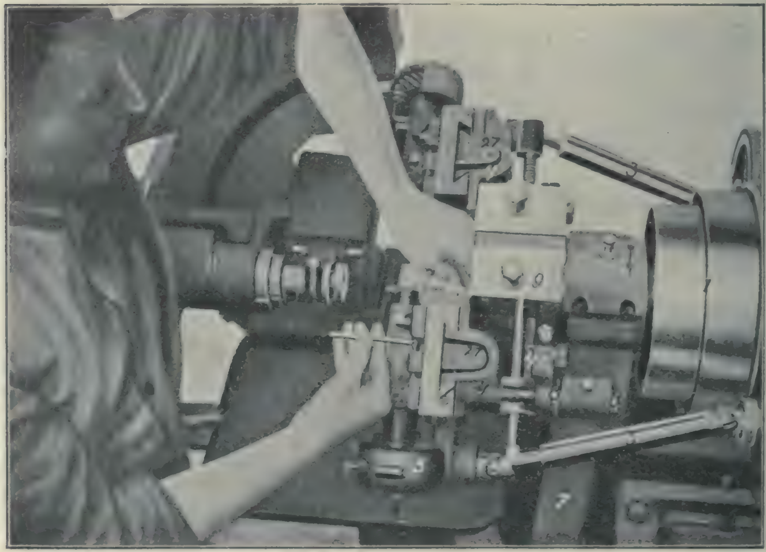


Fig. 366. Lateral adjustment of cutters.

The return clutch is driven by the bevel gears 30 mounted on a shaft running transversely through the column and driven by the bevel gears in the gear box 31, (fig. 367). The return feed is further transmitted by clutch 29, (fig. 364), and the gears in gear box 25 to shaft 26, through the spiral gears in the cutter slides 4 to the feed screws 27 of the cutter slides, and returns the latter with increased feed to the top.

The feed of the cutter slides is engaged and disengaged by pins 32 and 33, (fig. 364) on the drum 34, (which is connected with wheel 35 by means of differential gears), the levers 36 and 23 and pin 28.

The down feed of the slides can be adjusted according to the width of face of the teeth of the bevel gear blank by adjusting the adjustable pin 32 in the groove of the drum 34.

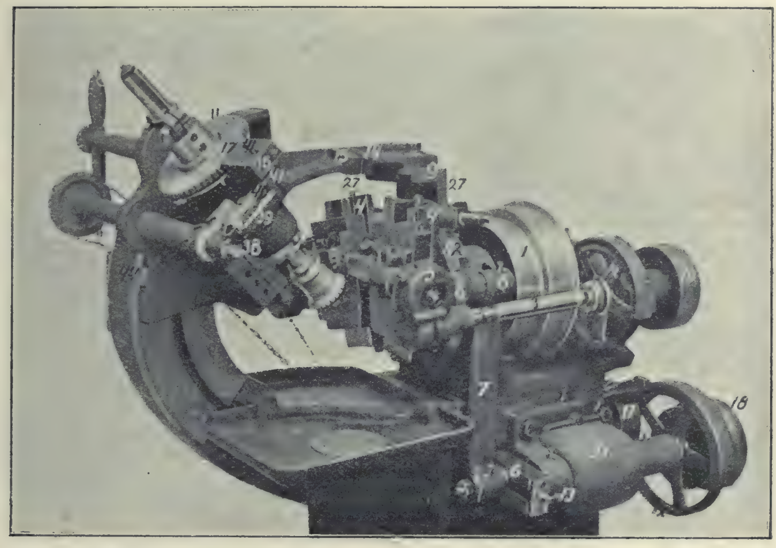


Fig. 367. Adjustment of the cutters to the exact angle of the tooth.

The movement of the bevel gear blank one tooth further on takes place at the termination of the return stroke of the cutter slides. Shaft 37, (fig. 364), imparts motion to spindle 38 by means of a driving chain, which spindle makes approximately a half turn to and fro each time that the feed motion of the cutter slides reverses. At the right hand end of spindle 38 is a connecting flap 39, (fig. 365). During the down feed motion this flap moves slowly downwards; on its return, it reverses quickly with lock 40 against pin 41. Pin 41 rocks with arm 16 and the gear blank. In this way, when the connecting flap 39 is at the highest point, pin 41 will slide off along the slanting surfaces of lock 40 and withdraw the pawl from the index plate 17. The index plate 17 and the blank remain stationary, arm 16 with the pawl rotating and turning the blank one tooth further on.

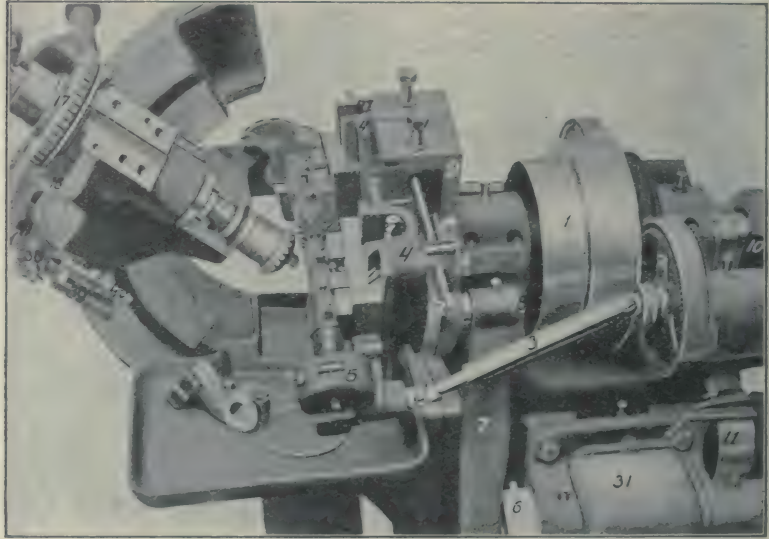


Fig. 368. The machine ready to work.

The adjustment of the machine.

The cutters require to be accurately adjusted in three ways. Fig. 365 shows the adjustment according to the diameter. In the place of segment 15, (fig. 364), is set the caliper 48, by means of which the cutters are so adjusted that their circumferences traverse the centre of the imaginary flat gear wheel.

Fig. 366 shows the lateral adjustment of the cutters. The inside "a" of the cutter must also traverse the same point. Fig. 367 further shows the divided scale 42 with micrometer adjustment which serves for the adjustment of the slides at the proper angle.

The workpiece is first adjusted at the angle $(a + \delta)$, then set against the cutters by screw 43, (fig. 364), in such a way that the sides of the teeth converge to the apex of the cone, being finally adjusted at its exact position at the correct angle $(a - \delta_1)$. These adjustments are rendered possible by the use of the divided scale 44, (fig. 367), and micrometer adjustment.

The bevel gears shown on the machine in figs. 367 and 368 are first stocked on a universal milling machine. For this machine, as in the case of the bevel gear planing machine, the preliminary cutting of grooves is a necessity.

(*g*). VERTICAL MILLING MACHINES.

The many good qualities of the vertical milling machine for machine manufacture in general cannot be easily overestimated. If the universal milling machine is an exceptionally valuable tool for machine manufacture in general, the vertical miller takes a still higher place, though it is a tool that is not used as generally as it deserves to be.

Large factories have learned to appreciate this type of machine at its true value but in a greater number of average size factories, this machine is conspicuous by its absence. In reply to the query "what can be accomplished on a vertical miller?", Herbert answers:—

Surfacing
Edge milling
Circular „
Keyway cutting
Cam „
Under „
Profiling
T-slot „
Recessing
Routing
Die sinking
Cotter hole milling.

From this it can be said that a vertical milling machine is par excellence a machine for general work. Indeed, we should strongly advise every manufacturer to begin with the adoption of a vertical miller. In chapter XIII dealing with work on the milling machine, the diversity of the work which can be carried out on the vertical miller is considered in detail since this chapter will deal with the machine exclusively from the constructive point of view. The leading manufacturers of vertical milling machines, such as Brown and Sharpe, Herbert, Cincinnati Milling Machine Co. Reinecker, Loewe, etc. build these machines for general milling work in three sizes, viz: No. 1, 2 and 3, differing but slightly from one another in their chief dimensions, their construction being wellnigh perfect. Fig. 369 is an illustration of the No. 3 Brown and Sharpe vertical milling machine. The leading thoughts embodied in this machine are:— single pulley drive; all drives transmitted from the main drive by gearing; the handling of the machine within easy reach of the operator.

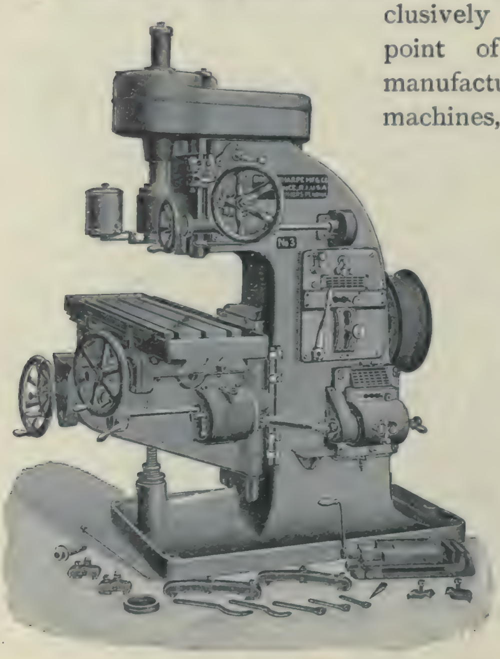


Fig. 369.
Brown and Sharpe single pulley vertical milling machine.

The chief dimensions of this machine are:—

Longitudinal	feed of the table	34″.
Transverse	, „ „ „	13½″.
Vertical	„ „ knee	15″.
Vertical	„ „ the spindle head	8″.

all feeds being fully automatic.

Fig. 370 gives a sectional view of this machine. The drive of the whole of the machine is derived from the main shaft C. The vertical main spindle derives its motion from shaft C through gearing. Eight rates of speed are imparted to shaft E by a train of gears inside in the column through the bevel gears near B, whilst by means of a clutch, the upper or lower vertical bevel gear can be made to mesh the horizontal bevel gear and thus the spindle E can impart the eight speeds either to the right or to the left.

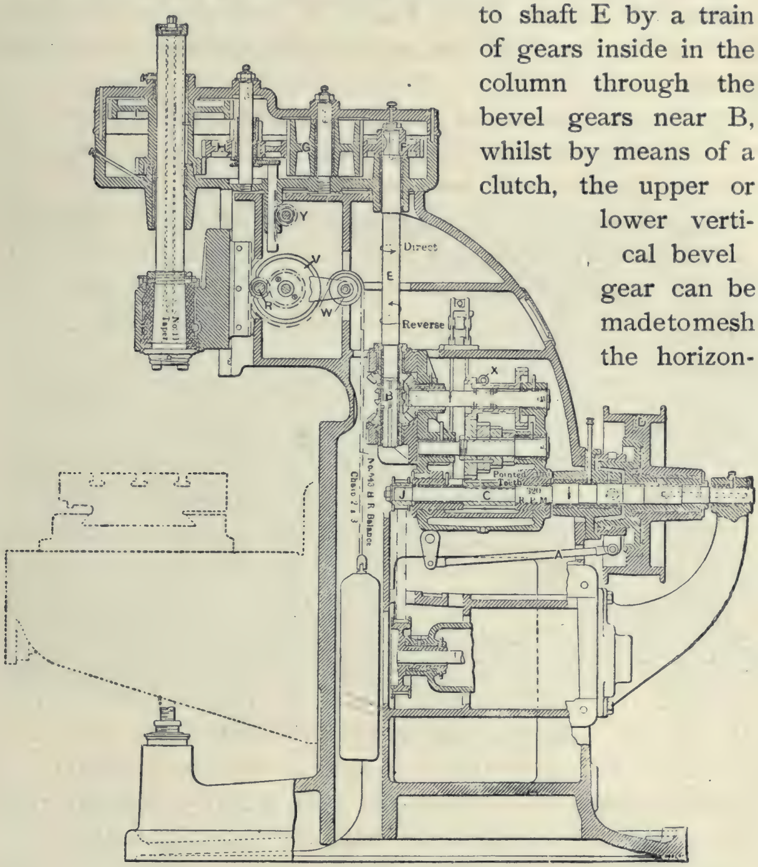


Fig. 370.
Sectional view of Brown and Sharpe vertical milling machine.

Drive is further transmitted from spindle E and the main spindle by spur gears, the main spindle being driven by F, G and H on the pinion on the spindle, (quick speed), or by F, G, pinion H on the large spur gear on the spindle, (slow speed), so that in all, with a constant speed of the pulley, $2 \times 8 = 16$ rates of speed can be imparted to the spindle in either direction simply by shifting three levers.

The machine is provided with variable feed mechanism giving 16 positive feeds driven by a Renold's chain from the shaft C, the feed being thus independent of the spindle speed.

From the lower gear case on one side of the column, feed motion is imparted to the telescopic feed shaft, from whence the longitudinal and transverse feed of the table and the vertical feed of the knee are derived and further feed motion is transmitted to the spindle head and, if one is provided, for the rotary motion of the circular table. A total of 5 automatic feeds can thus be obtained, each of which has 16 rates of feeds.

The main spindle speed. The belt driving the machine runs on the pulley D, on the shaft C. The machine can thus be driven direct from the line shafting, the pulley being provided with a friction device which can be handled by a vertical lever in front of the column. The machine is thus started and stopped by this lever.

The speed changing mechanism which is shown separately in fig. 370, is very simple.

An idle wheel fig. 370 between the long pinion on C with the cone gear above it can be made to mesh in one of the four gears of this cone thus imparting 4 speeds to the shaft on which the cone gear is mounted, the number being doubled when either the gear wheel or the pinion of the topmost shaft is meshed in the cone gear by means of X. This mechanism resembles to a great extent that for the feed change, the only difference between them being the location of the levers. The position of the levers can be clearly seen on the front of the gear box shown in fig. 371 on top on the left hand side. An index plate gives the number of revolutions for each position of the levers. The lever for reversing the motion is the one to the extreme left on the front.

The eight rates of speed of the vertical shaft E can, as has already been said, be doubled by means of the gearing in the gear box on top of the column by shifting the lever located on the column just above the hand wheel for the adjustment of the spindle head.

The feed mechanism is driven by chain and sprocket wheel on the horizontal shaft B (fig. 372).

This gear box is shown in the right-hand upper corner in fig. 371. On the shaft B are mounted the gear wheel C and pinion D; by shifting the lever which can be seen on the gear box in fig. 371, the gear can be placed in the central position so that the feed mechanism is disengaged, either C or D being in mesh with the corresponding gears on shaft E. Two rates of speed can thus be imparted to shaft E. The middle portion of this shaft is formed as a pinion. An idle wheel meshing in this pinion, not visible in the illustration, can be moved laterally so as to mesh in one of the four gears of the cone on shaft F, to which shaft 2 × 4 = 8 rates of speed can consequently be imparted. The lever G to the right of the gear box, enables the different distances required for the difference in

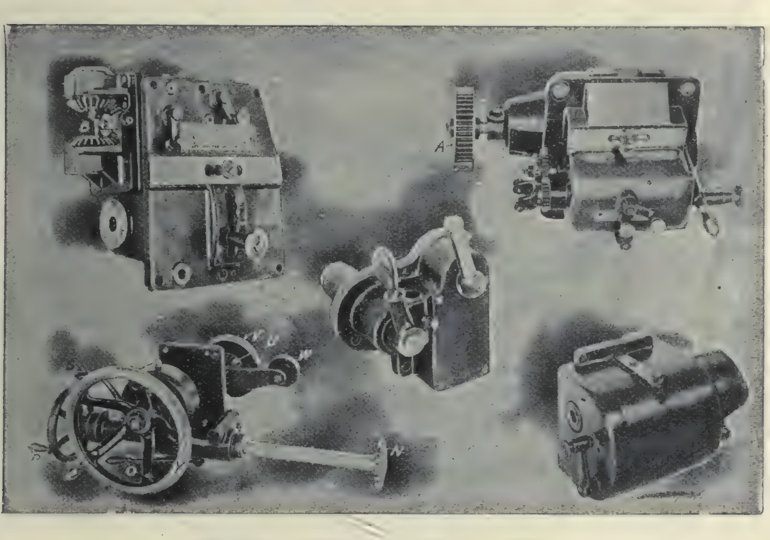


Fig. 371. Feed and speed gear boxes.

diameter of the wheels to be obtained, whilst the knob which can be seen just under the index plate in fig. 371, shifts the idle wheel opposite one of the gear wheels on shaft F. The eight rates speeds of shaft F are again doubled by shifting the double wheel H on shaft J so that either the largest wheel of the cone on F meshes the pinion on J or vice versa by means of the upper of the two lower levers to be seen on the gear box in fig. 371.

For each speed of the main spindle, 16 speeds can thus be imparted to shaft J which finally drives the telescopic shaft.

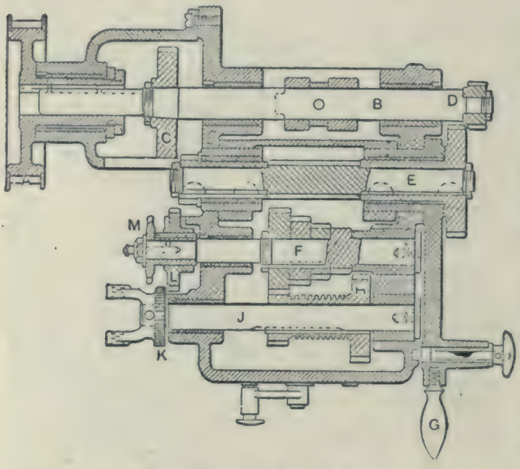


Fig. 372. Feed gear box.

The automatic feed is consequently driven by the telescopic shaft to be seen in fig. 369 to the right hand side of the column between the two feed gear boxes. By moving the lever to be seen in front of the knee gear box the motion of this shaft can be reversed. This gear box is separately depicted in the right-hand lower corner of fig. 371. By means of gearing, the motion is conducted from this gear box to the feed screw which gives the longitudinal movement to the table or to the mechanism for the transverse movement of the cross piece and the vertical feed of the knee. The two latter motions are engaged by levers and clutches inside the gear boxes for the transverse and vertical feeds shown in the centre of fig. 371. This box is to be seen on the right-hand side of the knee in fig. 371. The automatic right and left-hand longitudinal feed of the table is engaged by the lever immediately in front of the table.

By means of the large hand wheel in front of the knee, the table can be moved either slowly or quickly by hand, while this handwheel, if desired, can be disengaged entirely by means of a knob in the centre of this hand wheel. All the hand wheels can be disconnected so as to run loose on their studs; the hand wheels are provided with dials graduated to read to thousandths of an inch.

The automatic vertical feed of the spindle head is driven by the same mechanism as that for the other feed motions.

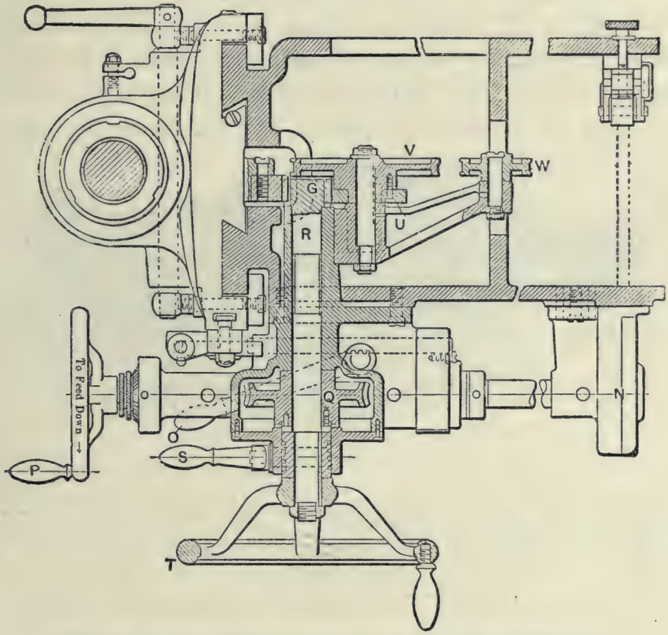


Fig. 373. The vertical feed mechanism of the spindle head.

On the left-hand side of fig. 372, a gear wheel is to be seen on shaft J just behind the fork. By means of a lever, gear L on shaft F can be made to mesh K and as L is mounted on the hub of the sprocket wheel M, the latter is consequently set in motion. From this wheel a chain runs over two loose sprocket wheels inside the column to a sprocket wheel N, to be seen in the left-hand lower part in fig. 371 as also in fig. 373. A lever O locks this wheel N with the worm shaft to which the hand wheel P is keyed.

The clutch is tripped by the feed tripping dogs at the side of the spindle head which can be adjusted along T slots at the side of this head. A worm on the hand wheel shaft for the slow hand movement of the spindle head meshes the worm wheel Q mounted on shaft R. Q can be engaged and dropped by the lever S. If Q is dropped, the spindle head can be raised and lowered quickly by the hand wheel T, whilst by means of the hand wheel P, the head can be raised and lowered slowly to permit of accurate adjustment.

The pinion G at the extremity of R meshes a rack at the back of the spindle head. This pinion also meshes gear U mounted on the hub of the wheel V. A steel cable is fixed to V and is guided by pulley W inside the column, a counterweight being attached to the end. The counterweight is encased to prevent its swinging (fig. 370).

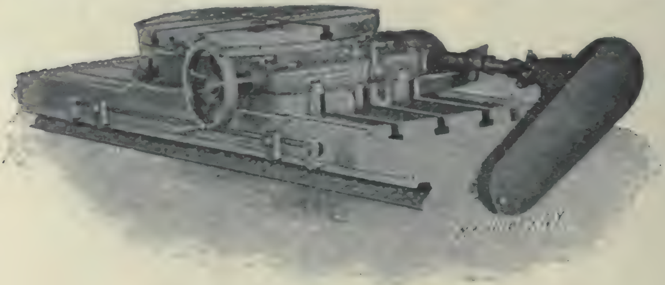


Fig. 374. The circular table.

Such a vertical milling machine as is here described is not suited for general work unless provided with a circular table. For at least 50 % of general shop work this circular table is certainly in use. Fig. 374 shows the circular table mounted on the square one. The automatic rotary movement is derived from the shaft driving the feed screw which provides the longitudinal movement of the table. For this purpose the connection between lead screw and this shaft is broken, so that only the circular table rotates, the square one remaining stationary. For the longitudinal movement of the table by hand, a square is provided at the end of the lead screw for a crank handle.

The circular table feed is engaged, dropped and reversed by a lever at the right-hand side of the circular table. The dogs for feed tripping are located in a T slot on the circumference of the table.

A feature worthy of note in this machine is the manner in which the different mechanisms are located, the speed mechanism, that for the feed, for reversing etc. being housed in separate boxes. This is a great advantage not only from the maker's point of view but also in the actual handling of the machine. Should one of the parts of the mechanism require repair, the particular box can be taken out the column so that all parts can be easily got at. This is only possible if each mechanism is wholly independent of the other.

It formerly cost much trouble and loss of time to dismount machines with the result that minor parts were damaged, whereas the whole machine can now be quickly dismounted without injury to the smaller parts by taking out the gear boxes.

The Brown and Sharpe machine described has a vertical sliding head in addition to a vertically adjustable knee. In the smaller type machines this is the rule but in the larger types it is not so easy to construct machines with a vertically adjustable knee guided by bearings along the column surfaces so that the table is then only horizontally adjustable in both directions and travels over a bearing forming part of the column, the spindle head being vertically adjustable along the column.

Recently the Cincinnati Machine Tool Company has put on the market a vertical High Duty milling machine of very modern and up-to-date construction, especially as regards its single pulley drive which is similar to that used on the Brown & Sharpe milling machines, which is designed to take the heaviest cuts at the quickest feeds the work is capable of withstanding. Really, under certain conditions this machine has more power than a cutter of the very best quality is able to absorb or the toughest material demand. Fig. 375 shows the general form of this milling machine.

It will be seen that there is not such a great difference in its construction to that of the universal single pulley milling machine illustrated and described on pages 242—250, the main difference being that the head is vertical instead of horizontal. It is, therefore, unnecessary to give a detailed description of the drive, the feed mechanism and construction of the table, since this has already been given in the pages referred to above. The sliding head spindle and spindle drive are illustrated in fig. 376. The drive is direct from the main driving gearing, through corresponding mitre gears. The gear on the spindle is so located as to bring the drive as close to the lower bearing as possible, thus reducing the possibility of torsional pressure. The spindle has bearings of the same size and is of the same length as the spindle of the universal milling machine described on pages 242—250. From this it will be seen that the designer has introduced

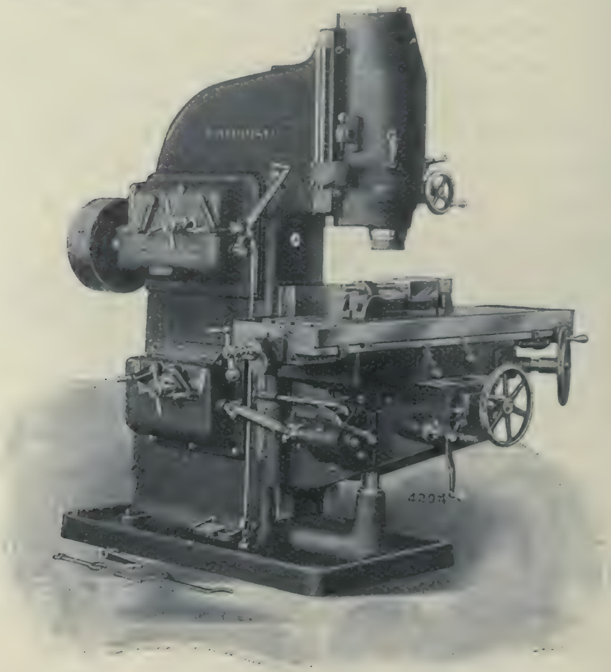


Fig. 375. Cincinnati Vertical High Duty milling machine.

quite a new principle, viz:—the construction of a vertical milling machine on entirely the same lines as the universal milling machine with the exception of the head being in a different position, i. e. *vertical* instead of *horizontal.* The spindle bearings are both carried in the sliding head (fig. 377), and are, therefore, always at the maximum distance apart for every position of the head, thus differing considerably

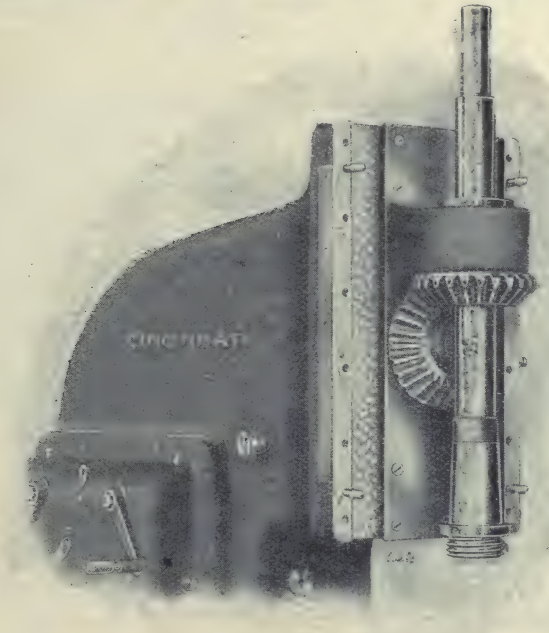


Fig. 376. Spindle and driving gears.

from the Brown & Sharpe construction, sectional view of which is given in fig. 370, where the distance is variable, the minimum distance being when the sliding head is at the highest point and the maximum distance when the head is down. The vertical sliding head shown in fig. 377 has a long bearing surface with provision for taking up wear by means of a tapered jib. An adjustment is also provided for correcting the vertical alignment of the spindle. In case of repetition work requiring heavy cuts, the jib screws may be tightened so as to fit the sliding head tightly to the main body, thus holding it in an absolutely fast position. The sliding head may be slowly adjusted vertically by a hand wheel situated at the front of the head which is brought into engagement by means of a positive clutch operated by the handle at the end of the main shaft. This slow movement is provided with a micrometer dial. A turnstile is provided at the side of the head for quick adjustment at the rate of 6 inches per turn. The end stop at the side of the head is also fitted with micrometer adjustment.

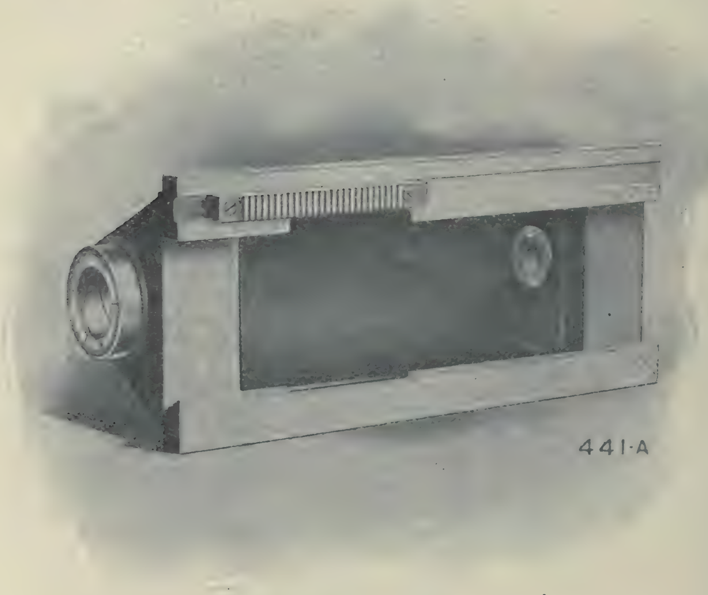


Fig. 377. The sliding head.

The machines described above are adapted for all the different kinds of milling work necessary in shop practice. Moreover, a large number of vertical millers are used as special machines, amongst which profiling machines occupy a leading place.

Many vertical milling machines for general milling work are also arranged for profile milling. As a general rule the larger types of vertical milling machines for general milling work, are at the same time arranged for profile milling, but not the smaller sizes.

Fig. 378 shows a vertical milling machine manufactured by Herbert, having a longitudinal table feed of 62 inches and a transverse feed of 38 inches, so that it is a machine of comparatively large dimensions, the sliding head being vertically adjustable over a length of 19 inches, whilst the machine is also arranged for profile milling.

The machine is driven by a four-step cone pulley. From this cone pulley the drive is transmitted to the main spindle by a belt running on a pulley mounted on the same shaft as the cone pulley and from thence by way of two guide pulleys to the pulley which drives the main spindle. This pulley runs on a sleeve independent of the main spindle, which prevents any belt pull on the latter, the pulley driving the spindle by means of a clutch which permits of the spindle being started and stopped independently of the belt drive. The spindle is bored through its entire length, the cutters being held in place by a draw bolt. This spindle has 16 rates of speed. The spindle head with the spindle is vertically adjustable, while the driving pulley remains in place and the main spindle runs free through its sleeve.

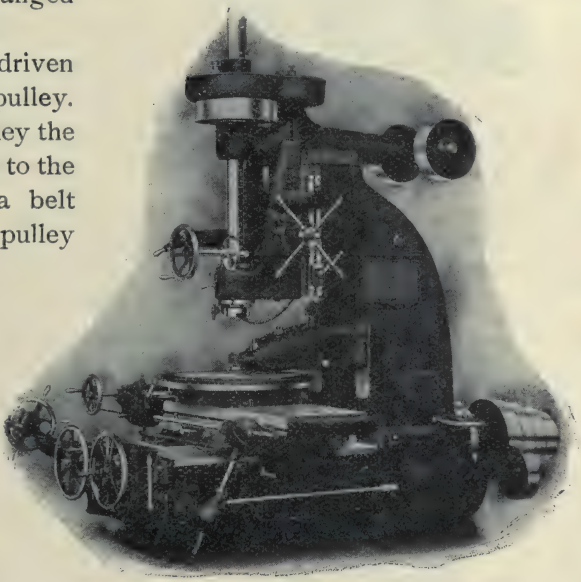


Fig. 378. A Herbert vertical milling machine.

At one side of the column is a steady bracket for carrying the lower end of the arbor for heavy milling, thus affording the arbor a support on the underside. This bracket can be adjusted vertically in two positions so as to permit of its being used with the circular as well as with the main table. When not in use, this bracket can be swiveled back out of the way of the table.

For profile work a profiling roller can be attached to the bracket. The profiling roller can be accurately adjusted by means of a screw so that the roller can be placed correctly for putting on the cut. The roller and the arbor support are entirely independent so that both can be used at the same time.

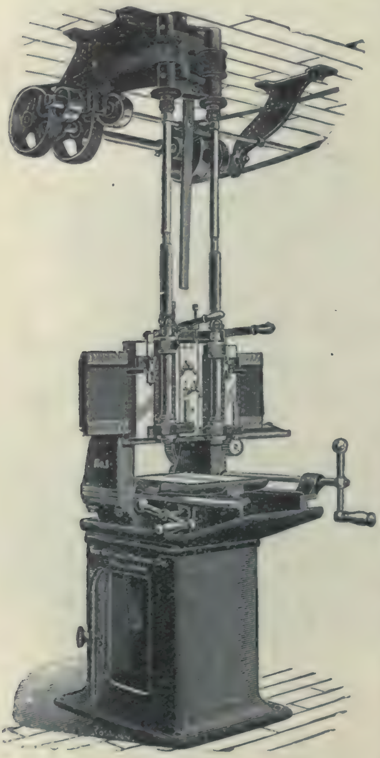


Fig. 379.
Profile milling machine.

The Garvin Machine Co. makes a special profiling machine as illustrated in fig. 379, the general lines of which remind one very much of a small planer. The table with the workpiece runs in straight tracks square on the cross bridge over which the spindle slides travel in a horizontal direction. The drive of this machine is effected in a special manner from the countershaft without the employment of a belt. The upper end of the spindles terminates in a universal joint, (fig. 380). The machine shown in fig. 379 is a two-spindle profiling machine so that the workpiece can be roughed out by one spindle and finished with the other without resetting or requiring any change of cutters.

The table and cross slide are moved by rack and pinion. The table has automatic longitudinal feed and is provided with reverse and automatic trip. The workpiece is mounted on the table side by side with the form. The former pin travels along this form, being mounted on the spindle slide with the spindle.

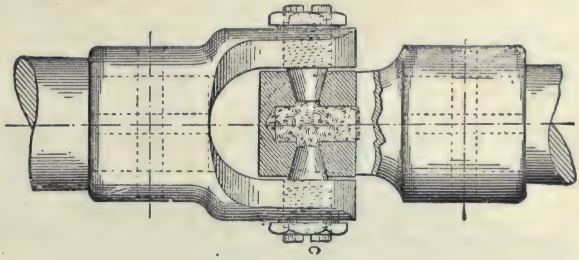


Fig. 380. Universal joint.

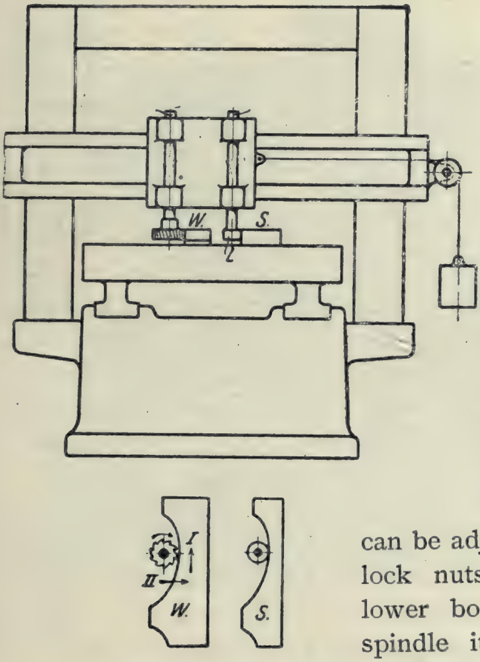


Fig. 381. Profile milling.

Fig. 381 gives a view of the manner of working, whilst fig. 382 gives a sectional view of the construction of the spindle and former pin. The spindle bearings are tapered top and bottom. Hardened and ground thrust washers are placed on both sides of bottom and under side of top bearing. The spindle is shouldered on the lower box, the end thrust being taken up by a steel washer. A hardened steel taper sleeve runs in the upper bearing, and is keyed to the spindle allowing freedom for expansion. Each of the bearings can be adjusted independently by lock nuts. In the case of the lower box, this nut is on the spindle itself so that its journal can be drawn in the tapered box, whilst for the upper bearing the nut is on the lower end of the sleeve. The former pin is mounted in a extended boss in the casting by side of the spindle and can easily be fitted. The slide is balanced by the long spring inside a tube as shown by the side of the spindle. The tension of the spring can be altered at will by means of a screw at the top of the tube.

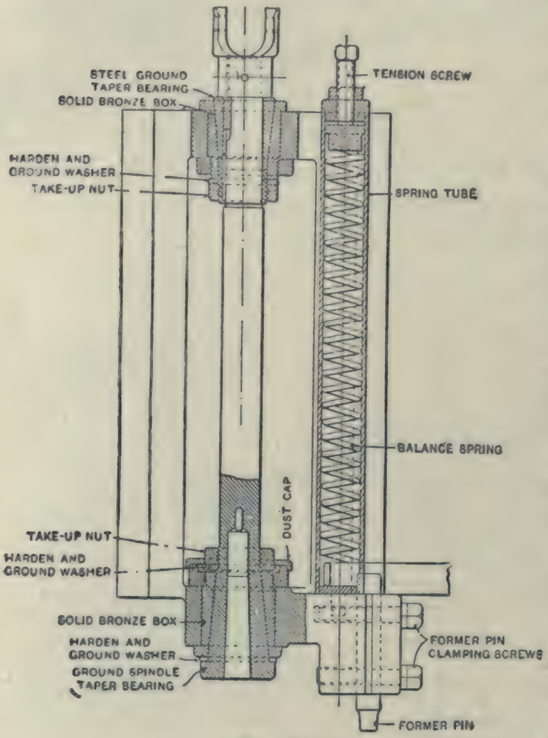


Fig. 382.
Sectional view of main spindle of profile milling machine.

This profile milling machine is also constructed as an ordinary vertical miller and as such, is illustrated in fig. 383.

This type is not a machine for general milling work, its use being limited to surface milling, shaft splining and drilling and the boring of holes in .workpieces machined on this machine, for which it is eminently adapted.

The spindle head is carried on a vertically adjustable cross rail whilst the spindle itself can be quickly adjusted vertically by hand over a sufficient length to permit of the spindle being set to the desired position. The spindle is balanced whilst the head is moved one inch for each revolution of the hand wheel in front of it. The spindle head is moved along the cross rail by feed screw. The spindle head can also be adjusted in both directions and is provided with automatic feed trip. The cross slide can be adjusted vertically by hand and clamped to the housings at any desired height. As in the case of fig. 379, the spindle is driven direct from the countershaft by a telescopic shaft without belt transmission. Motion is transmitted from the telescopic shaft to the spindle through two sets of spur gears, each with a different ratio, so that for each speed of

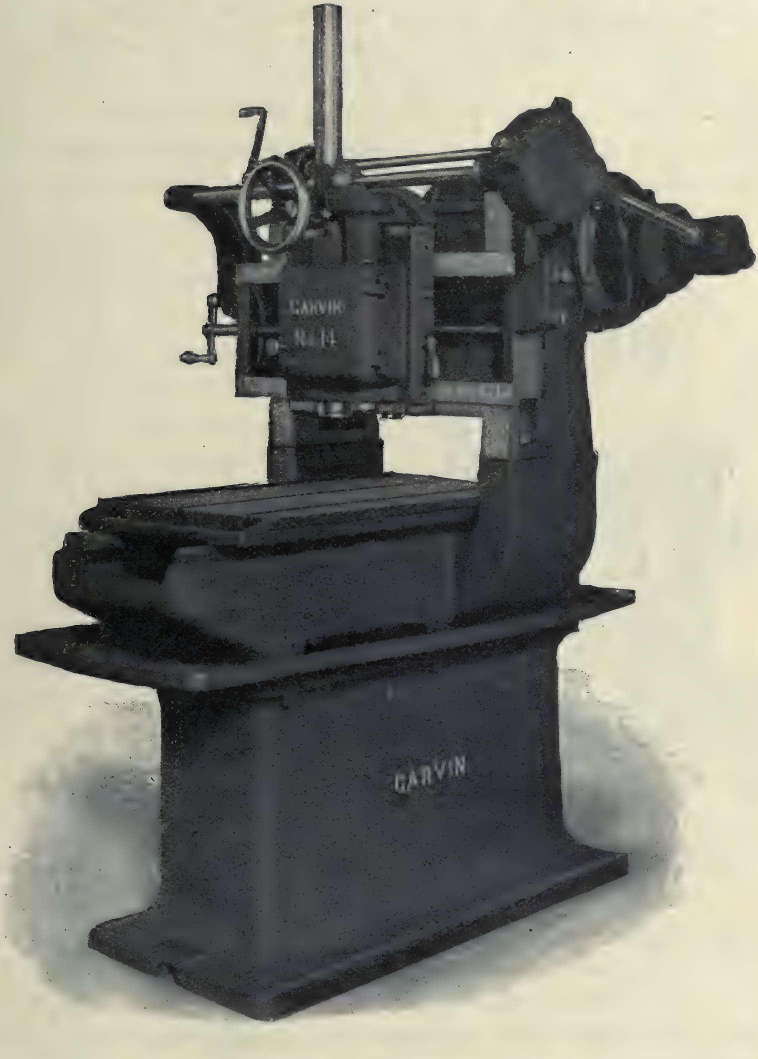


Fig. 383. Garvin vertical spindle milling machine.

the telescopic shaft, two rates of speed can be imparted to the spindle. Since three speeds can be imparted to the former, the spindle has six rates of speed. In the larger sizes, the machines are provided with back gear which allows of twelve rates of speed being imparted to the spindle.

The feed is driven from the countershaft by a single pulley through a feed gear box giving ten rates of feed which can be changed instantantly by shifting levers. The gearing runs in an oil bath in the gear box.

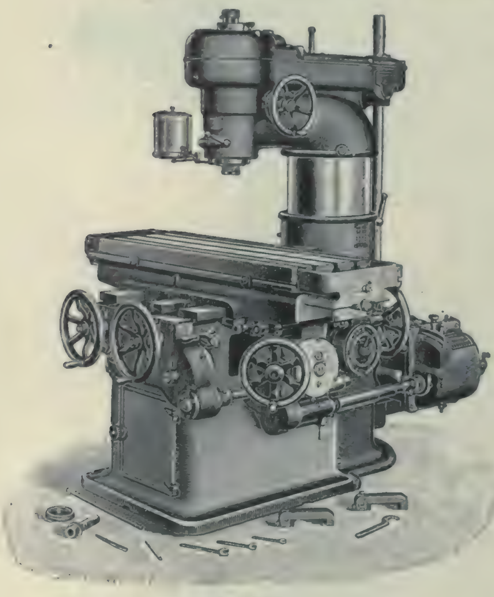


Fig. 384.
Brown and Sharpe vertical spindle milling machine.

Fig. 384 shows a very different type of vertical milling machine. This machine, manufactured by Brown and Sharpe, consists of a box shaped bed on which a saddle and a square table travel in both longitudinal and transverse directions. At the rear is a round column vertically adjustable by hand by means of a hand wheel in its housing. Motion is imparted to the main spindle from the main drive by a vertical shaft and gearing inside the bed and column. The table has longitudinal feed in the saddle and the latter transverse feed on the bed driven from a feed gear box of the same construction as that shown in fig. 369 with feed tripping mechanism whilst the spindle bearings are the same as those shown in the sectional view in fig. 370.

Fig. 385 gives a sectional view over the spindle bearing of a Hessenmüller vertical milling machine. The bronze lower box in the spindle head, tapered on the outside, cylindrical on the inside, is split over its entire length, the top and bottom being threaded for adjustment after wear. In the top nut of the lower box are washers for taking up the end thrust. A flat ring is fixed on the spindle and runs between two hardened steel washers which can be adjusted by nut and locknut. The box is provided with felt lubrication. The spindle has a conical bore and threaded nose to receive cutters and cutter arbors which are clamped by a differential nut.

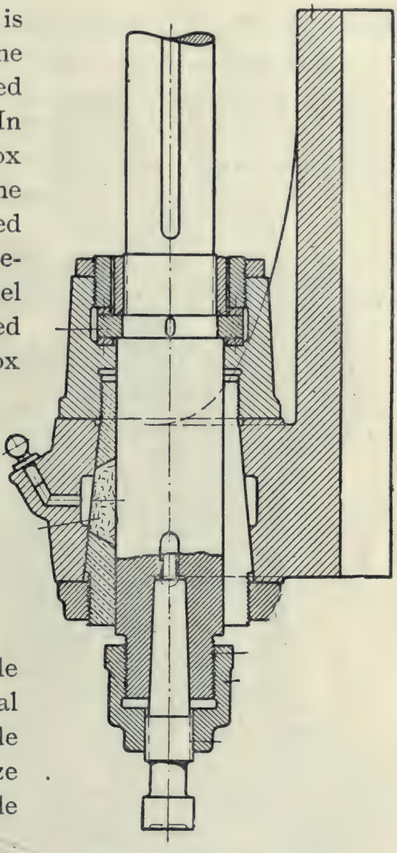


Fig. 385.
Hessenmüller spindle bearing.

Fig. 386 gives a sectional view of the spindle bearing of a Reinecker vertical milling machine. The spindle journal is tapered, the bronze box cylindrical on the outside being fixed in proper position by top and bottom locknuts.

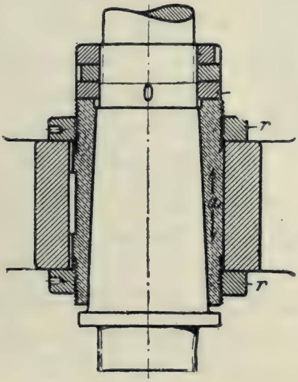


Fig. 386.
Reinecker spindle bearing.

(*h*). SUNDRY MACHINES.

Besides vertical milling machines with two spindles, machines are also built with two horizontal spindles. Fig. 387 shows one of the smaller machines of this type. These machines are exclusively used for the simultaneous milling of two parallel surfaces. The machine shown in fig. 387 is extensively used for milling hexagonals and squares of plugs, taps, etc. as also for nuts and bolts. For the last mentioned purposes especially this machine has of late come more and more into use for general shop work.

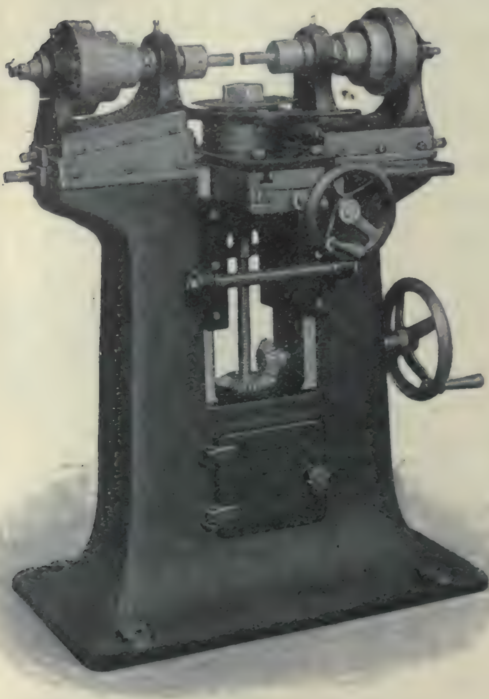


Fig. 387. Two-spindle horizontal milling machine.

For this purpose a divider is fixed on the vertical arbor by which the workpiece can be swiveled 180°, 90°, 60° and 45° so that squares, hexagons and octagons can be milled. Both spindles rotate at the same speed and the double edge cutter fig. 21 is used on this machine for milling brass work. Both headstocks can be adjustedhorizontally by means of micrometer adjustment but whilst at work remain in a fixed position. The left hand headstock is moreover vertically adjustable over a limited distance so as to permit of milling both shoulders equally with two cutters of different diameter. Should this vertical adjustment be lacking, it is necessary to use two cutters of precisely the same diameter if it be desired to mill two shoulders equally.

The table runs square to the spindles, is vertically adjustable by handwheel at the right-hand side of the column whilst the table has handfeed, the larger sizes in addition having power feed. The dimensions of the table are 14 × 7 inches, the larger size having a table 48 × 10 inches. The larger size is, however, no longer employed for milling small brass pieces as described above but for the parallel milling of castings such as are so frequently to be met with in general shop work.

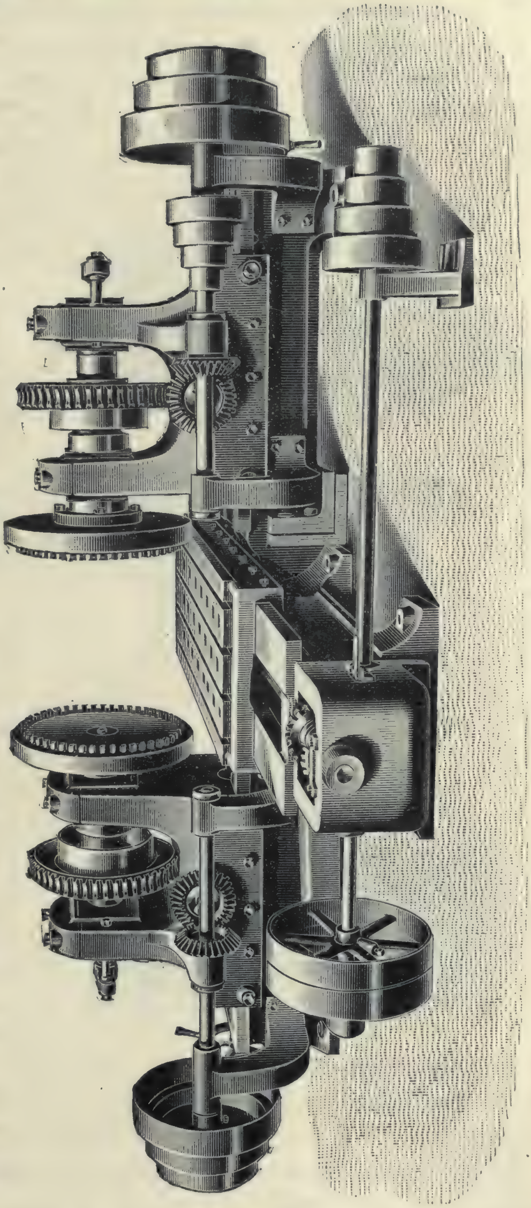


Fig. 388. Surface milling machine.

The still larger sizes of this type of milling machines are of the low built type shown in fig. 388. On these machines the ordinary cutters are no longer used but only face mills with inserted tooth as illustrated in fig. 10. They are used exclusively for milling large castings whilst very often only one cutter is used, as, for example, in the sectional milling of flywheels, pulleys, gear cases, etc. The main spindles are driven from a three-step cone pulley through a set of bevel gears by worm and wormwheel, which latter is fitted direct on the main spindle. The table has power feed square on the main spindles.

A small two-spindle milling machine is illustrated in fig. 389. In this machine the cutters are not face to face to each other but contrary. The cutters make 400 revolutions per minute, double edge cutters see fig. 21 being used on this machine. The machine is specially constructed for cutting small slots and keyways in automobile engine valves, etc.

The cutting is entirely automatic, that is to say, the table travels automatically to and fro, the reversal of movement being automatic, and the table travel can be limited at any desired point by means of stops at the ends whilst at every reversal of the table the work is fed against the cutter for taking a fresh cut.

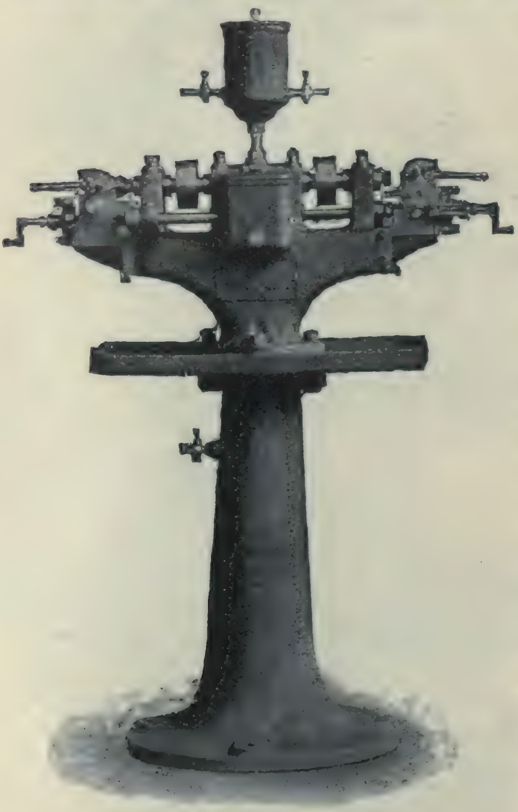


Fig. 389. Two-spindle keyway cutting machine.

The type of machine shown in fig. 390 is also employed as a slot drilling and keyway cutting machine. The table is vertically adjustable by hand and has a transverse movement on the knee, though during the operation it is clamped to the column. The spindle head has longitudinal movement over the cross rail both automatically and by hand in either direction, the reversal being also automatic whilst the reversal can be made at any desired point by adjustable stops. The spindle head is vertically adjustable whilst at every reversal the cutter is fed into the material for a fresh cut.

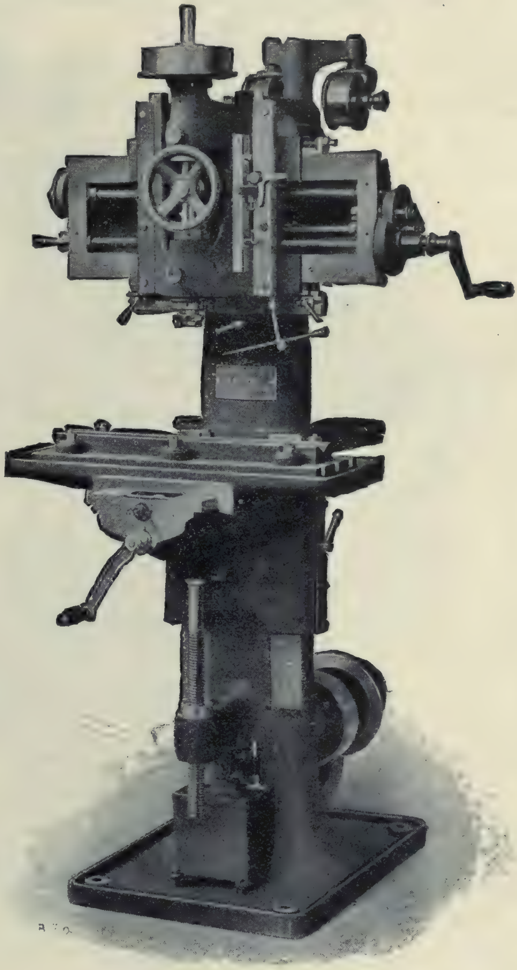


Fig. 390. Keyway cutting machine.

A special vertical milling machine is shown in fig. 391. This machine is used for rounding off the side faces of spur gear teeth which is necessary whenever two spur gears have to be put in mesh sideways, as in the gear boxes of automobiles, machine tools, etc. The diminutive cutter that runs vertically, makes 2700 revolutions per minute, describing a semi-circle around each tooth. The machine works fully automatically.

The gear of which the teeth have to be rounded off, is mounted on an arbor which is fixed between the centers of the two heads on the table. The table is vertically adjustable by hand as is also the main spindle, though only

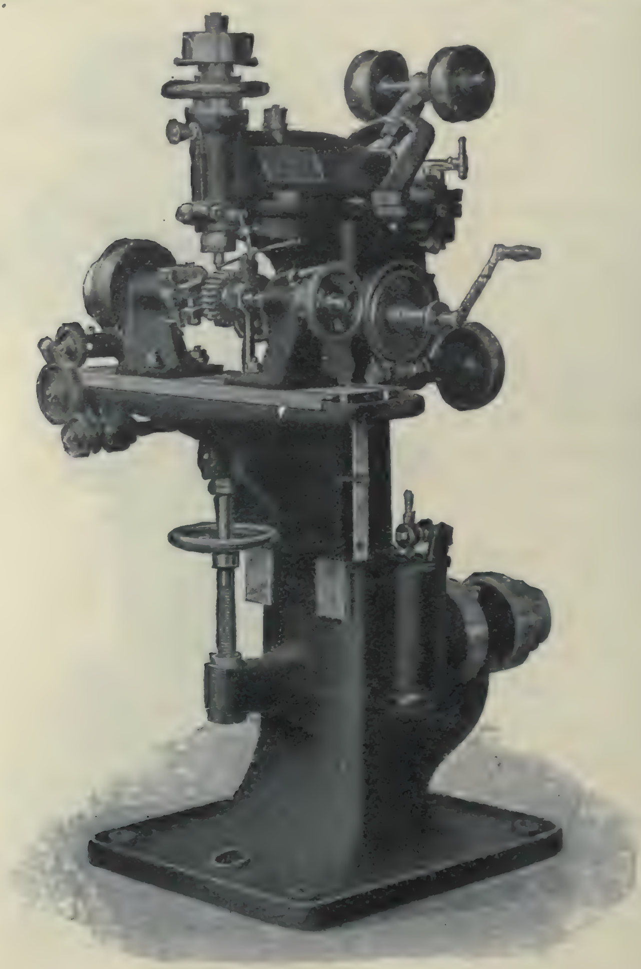


Fig. 391. Milling machine for rounding off the teeth of spur gears.

over an limited length. Parallel to the arbor on which the gear wheel to be milled is fixed, is a second arbor carrying a gear wheel which meshes the wheel to be milled and by which the gear wheel to be milled is turned during the operation.

When the machine has been properly adjusted and the cutter set at the exact depth and position as regards the teeth to be rounded off, the cutter is fed automatically round the tooth, the gear wheel being turned one tooth further on as soon as the preceding one is finished, so that the machine works fully automatically. It is not absolutely necessary that the rounding-off of the tooth should be a perfect semi-circle as, in order to facilitate the meshing of the teeth, they are usually somewhat more pointed.

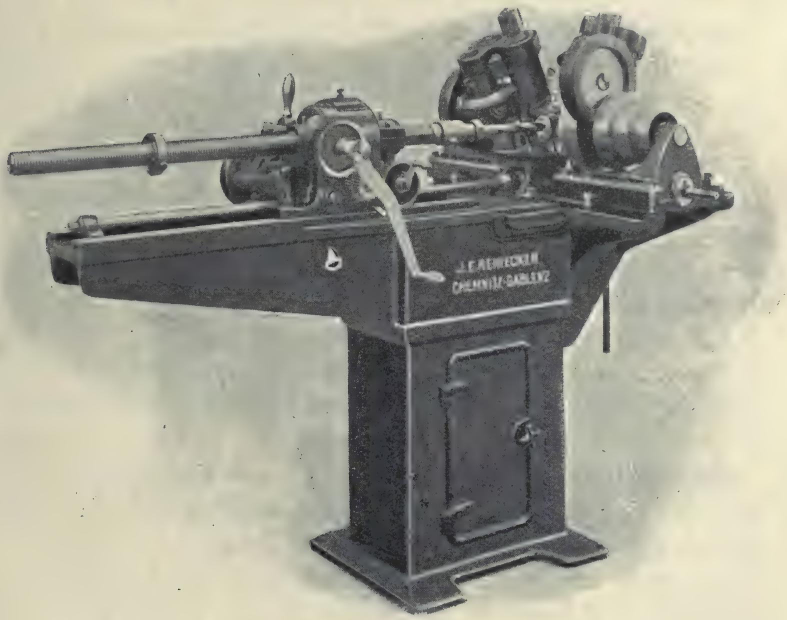


Fig. 392. Automatic twist drill milling machine.

Fig. 392 illustrates a twist drill milling machine built by Reinecker. The machine consists of two main parts standing square one to the other:—the two cutter heads and the head in which the twist drill blank is fixed and which is fed into the former. The two cutter heads are driven separately and are adjustable longitudinally to the table. The heads in which the arbors rotate can be placed at any desired angle in the vertical plane. Each of the cutters mills one of the two flutes, both being thus milled simultaneously, which is imperative since, if the flutes were milled separately, it would put too great side strain on the blank, with the consequent result, that the drill would not be straight.

During the operation only the two cutters rotate, both heads remaining stationary. The drill blank is fixed in the lead screw head square on the cutter heads.

Whilst operating, the lead screw travels longitudinally square on the cutter heads automatically whilst, at the same time, a slow rotating movement is imparted to the lead screw by change gears to be seen at the right-hand side of the lead screw head. By changing the ratio of the change gears, any desired lead can be obtained.

This manner of working is only applicable for twist drills with the same thickness of core over the whole length of the flutes.

The machine is, however, so constructed that drills can be made with a core increasing in thickness towards the end or with the same thickness of core up to a certain length after which the thickness is increased. In this case, the two cutter heads separate automatically and very slowly over a limited length from the centre outwards.

The flutes of drills up to 1 inch are deepened out completely in one cut, above 1 inch a second cut is necessary with a view to the metal to be cut away, the first cut for roughing, the second finishing. During the finishing cut, the outside surfaces of the drill are relieved at the same time.

Factories devoting themselves exclusively to the manufacture of twist drills, some of which turn out some 20,000,000 twist drills and more per annum, have constructed their own special machines for this work, which although very simple in construction, work entirely automatically and very quickly.

On these machines, some hundreds of which are in use in one factory, drills varying from $^1/_{64}$ inch—5 inch are made.

As, however, the manufacture of twist drills is the specialty of such factories, they are unwilling that the construction of their machines should be published.

(*k*). COMBINED HORIZONTAL AND VERTICAL SPINDLE MILLING MACHINES.

Combined horizontal and vertical spindle milling machines are to be met with in all the different types. Universal milling machines, vertical milling machines as well as plano-millers are built as combined machines, that is to say, one machine combines two or more types, as for instance, the horizontal milling machine is also constructed to work as vertical spindle milling machine, the plano-miller working either as vertical or rotary miller or both together.

These combined machines have been met with among the various types already described, inter alia, the Brown and Sharpe and Herbert vertical spindle milling machines which are also built as rotary millers, the Ingersoll milling machines which are built as vertical spindle- and plano-millers.

By combined machines we do not mean those which can be *changed* into another type by the temporary addition of a separate attachment, but rather those which unite the essential features of both types and which cannot be regarded either as vertical, horizontal or rotary milling machines and which owing to their special construction can only be considered as combined machines.

Fig. 393 illustrates a machine by Bariquand et Marre, represented in the illustration as a vertical miller.

The vertical spindle is driven from the cone pulley by a train of spur and mitre gears, and, fitted up as the machine is illustrated,, fulfills all the functions of a vertical spindle milling machine. The spindle head can be swiveled in a complete circle; the two bevel gears will still remain in mesh so that angular milling can be done. The head has only to be swiveled a half circle, whilst a cutter arbor or cutter is to be placed in the horizontal main spindle which projects from the front of the column in which it is housed, the arbor being supported by the overhanging centre to be seen on top which comes in line with the horizontal main spindle when swiveled 180°, and the machine is converted into a horizontal spindle miller. In order to prevent the vertical spindle running idle when milling horizontally, the small spur gear at the rear of the column can be thrown out.

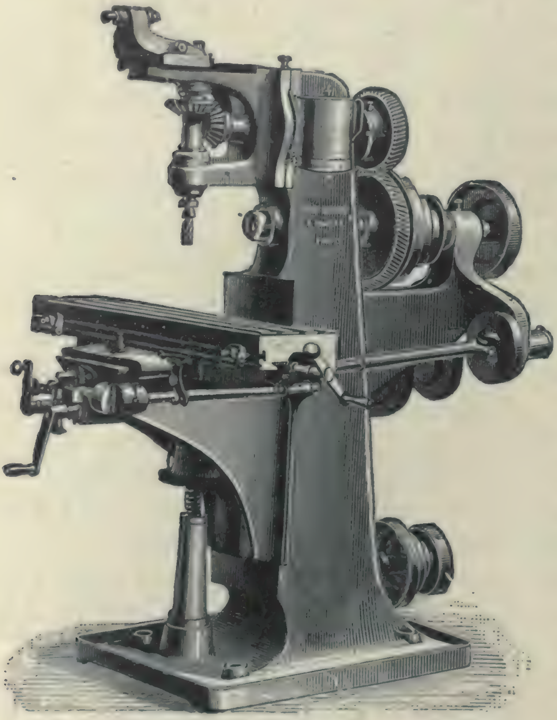


Fig. 393. Combined horizontal and vertical spindle milling machine of French make.

Fig. 394 shows such a machine built by Huré. Fig. 397 shows a sectional view of the spindle head, from which it can be clearly seen how the spindle is driven both horizontally and vertically or at any angle.

The spindle 11 to which the mitre wheel 5 is keyed, is driven from the cone pulley. This mitre wheel is always in mesh with the mitre wheel 6 in the swivel head 1 and 2 fastened to the column at 3 by ┬ bolts, and can be swiveled along this surface in a complete circle, (see fig. 397). The head is divided, the two halfs 1 and 2 being attached to one another at an angle of 45° also by ┬bolts, i. e. 1 against 2, the half head 1 which carries the gear wheels and the spindle being, as at 3, swivable in a complete circle. When set for horizontal milling, the position of the head is as shown in fig. 395 and 396, the drive being accomplished as shown in the sectional view.

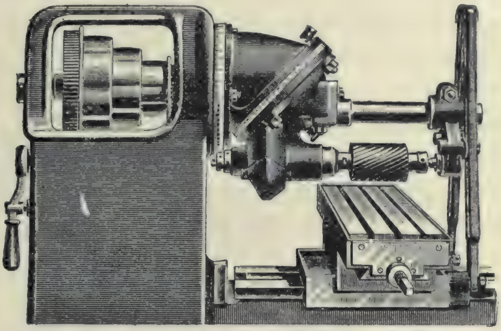


Fig. 394. Combined milling machine working as a horizontal machine.

The three mitre gears really act as two sets of gears, since 6 is the wheel driven by 5 as well as the driving wheel of 7 and for this reason provided with a double set of teeth. Wheel 5 thus drives 6 and 6 drives 7, whilst 7 is mounted on the spindle 4 carried in two conical bearings.

When swiveled over the surface 3, wheel 6 will travel over gear 5 and remain in mesh, since wheel 5 runs parallel to this surface. If, however, 1 be turned along 2, then the centre on which it turns will be the axis of wheel 6, wheel 7 will thus travel over wheel 6 and still remain in mesh. In whichever relative position the two halfs are placed, the three mitre wheels will still mesh one another.

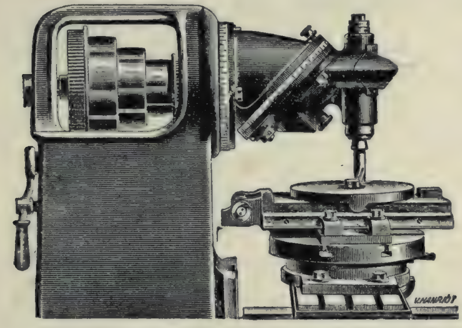


Fig. 395. Combined milling machine as a vertical miller.

If the half head is swiveled 180^0, the main spindle will have assumed every angle between horizontal and vertical. Seeing that the whole head can again be swiveled in the vertical plane at any angle from horizontal to vertical, it is possible to fix the main spindle as well at any angle.

Supposing that a half globe be attached to plane 3, the axis of the main spindle can be set at every radius from the centre of this globe to the circumference.

Figs. 394 and 395 show the horizontal and vertical position of the spindle, fig. 396 the spindle at an angle.

Both of the machines described here are of French make but cannot be regarded as examples of modern milling machine construction. In general, this type of machine is not employed in larger factories were horizontal as well as vertical machines are used, but chiefly in workshops where there is but a limited amount of milling work and where from time to time the need arises for a horizontal as well as a vertical miller.

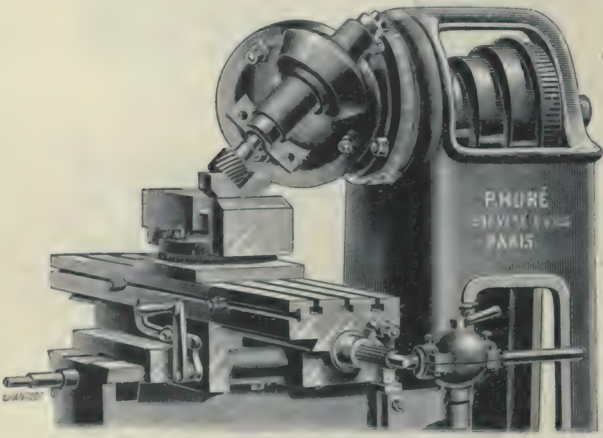


Fig. 396. Combined milling machine as a vertical miller working at an angle.

The increasing development of milling machines is bringing about a reformation even here and although the opinion has been expressed that the combined horizontal and vertical milling machine might be regarded as an out-of-date type, the Ingersoll Milling Machine Co. have brought out a combined horizontal and vertical milling machine of so up-to-date style and of such correctness of construction that it fully comes up to the present day position of milling machines and can consequently take its rightful place with the various other types. Fig. 398 gives a general view of this machine.

The general features of the column-and-knee type milling machine can be clearly recognized in this machine. The vertical milling attachment which almost every maker of column-and-knee type machines supplies separately, is definitely embodied in this machine. The reason for the introduction of the vertical milling attachment on the horizontal milling machine was: (1) to permit of carrying out milling work that could only rationally be done with a vertical spindle when no vertical milling machine was at hand, (2) to machine workpieces which require to be treated by a horizontal as well as by a vertical spindle on one machine without the necessity of resetting the workpiece. Mounting and later on dismounting a vertical attachment on a horizontal milling machine entails, however, a certain interruption in the regular course of work. In factories where either one or both these factors make themselves felt, the machine illustrated in fig. 398 is of exceptional importance and will certainly win a place for itself.

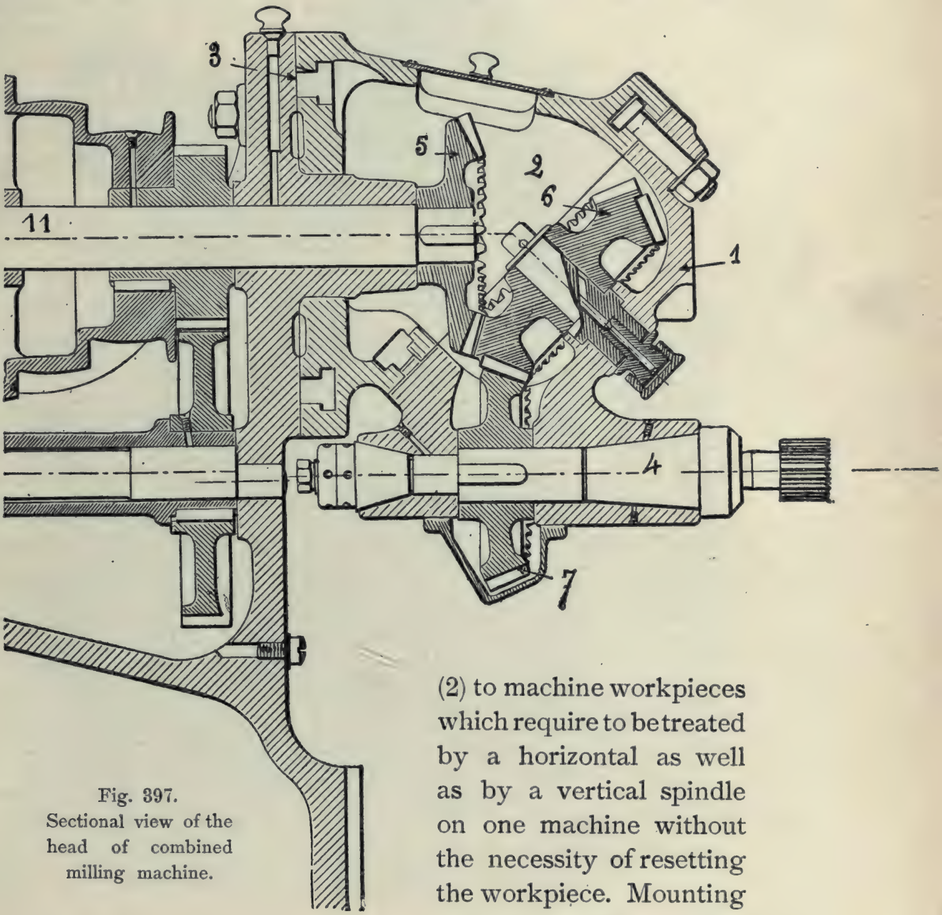


Fig. 397.
Sectional view of the head of combined milling machine.

It will be seen from fig. 398 that all parts underneath the horizontal main spindle correspond entirely with the construction of a column-and-knee type machine. The column is extended above the horizontal spindle to permit of the housing of the vertical spindle. In order to obtain the maximum transverse motion of the table, the column

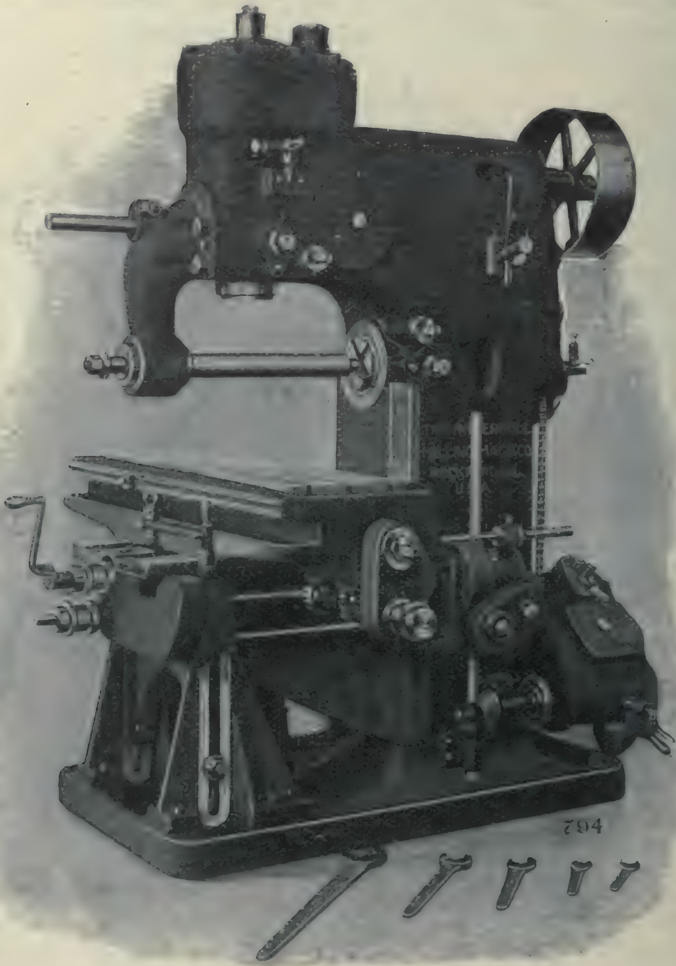


Fig. 398. Ingersoll combined milling machine.

above the horizontal spindle is built as strongly as possible, the knee, which is vertically adjustable over the column, being very long and supported at the outer end by braces. The machine is driven by a single pulley, all further motions being transmitted by gearing, whilst the feed motion is derived from a shaft running at such a speed that the feed motion is independent of the cutting speed.

Longitudinal, transverse and vertical power feeds are provided, all of them reversible and with automatic stops. The outer end of the main spindle is supported as in the column and knee type milling machine, whilst, though not shown in place in the illustration, bracings for connecting the outer support with the knee can be introduced. This machine is therefore, a tool which is in no way whatever inferior to the best constructed horizontal milling machine, whilst it combines within itself, the horizontal as well as the vertical miller.

Fig. 399 gives a sectional view of this machine. The driving shaft B is driven by the pulley A of large diameter and width which is keyed to shaft B. This shaft carries the sprocket C which drives the feed as also a double pinion which can be shifted over the shaft along a keyway so as to engage one of the two corresponding gears on shaft D. The double pinion is shifted by a lever on the outside of the column as shown in fig. 398. Two changes of speed can thus be imparted to shaft D.

From the shaft D motion is transmitted to shaft F by a bevel gearing, from which shaft it is further imparted to the vertical main spindle by spur gears.

The pinion E on shaft D meshes a gear on shaft J from whence motion is imparted to the horizontal main spindle. The horizontal and vertical spindles H H are of the same diameter, the driving mechanism for both being equally powerful.

Both spindles are carried in a sleeve W provided with a keyway and clutch teeth. These clutch teeth engage corresponding clutch teeth on the hubs of the gear wheels X and Y which run idle on W. The gears X and Y are driven by the corresponding pinions on shaft J for the horizontal and on shaft F for the vertical spindle. By shifting the clutches to the central position, both the horizontal and vertical spindles are stopped, whilst by engaging the clutches with either X or Y, two speed are obtained for each speed of shaft B. The sleeve W is shifted by the levers shown in fig. 398, one at the back of the column in line with the horizontal spindle, the other projecting from an opening in

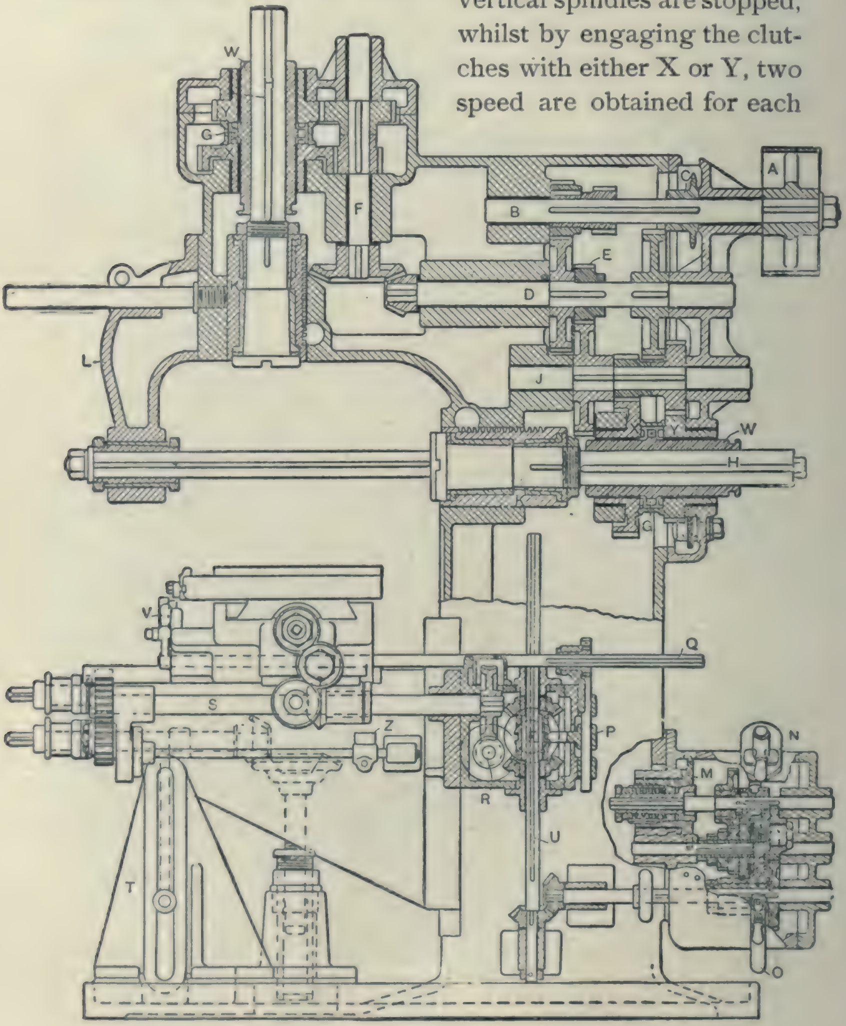


Fig. 399. Vertical section of the Ingersoll combined milling machine.

the vertical spindle housing. Four spindle speeds can thus be obtained for each of the spindles, with driving pulley A running at constant speed. With a two-speed countershaft, eight spindle speeds are thus obtainable for each spindle. The front housing of the spindles is contained in a sleeve K which can be adjusted axially by means of a pinion which meshes rack teeth cut in the sleeve K. This axial adjustment of the spindles is necessary to secure their correct position when working simultaneously (see fig. 401). The front housing of the horizontal and the lower housing of the vertical spindle consist of two tapered journals contained in sleeve K. The quills K are 12 inches long and have a lateral adjustment of 6 inches.

As previously mentioned, the feed is driven from a sprocket wheel C on shaft B so that the feed motions are wellnigh independent of the spindle speeds, being only increased or retarded once by the two speeds of the countershaft. The chain from the sprocket C drives the sprocket M in the gear box at rear of the base (figs. 398 and 399). This box contains a quick change gear mechanism. By shifting the lever O, eight feed changes are provided and this number is doubled by the handle N which imparts two speeds to a gearing that can transmit 8 speeds, giving 16 feeds in all. In order to provide a safety mechanism to prevent damage of certain parts of the machine, should anything happen, the sprocket M is not keyed directly to the shaft which it drives. Instead of this, the bore of this wheel is double tapered and supported by two taper cones pressed together by a spring. One of these cones has a long heel which is keyed direct to the shaft. The compression of these cones in the sprocket bore produces an adjustable frictional driving device which gives way in case of undue strain, though there is still sufficient friction to transmit the heaviest feeds required on the machine.

From the gear box comes a shaft which imparts motion to the vertical shaft V through a train of mitre gears.

The splined shaft U passes through a gear box attached to the knee and containing a clucth and bevel gear reversing mechanism operated by the fork P. The central bevel gear of this mechanism is connected by spur gears with the worm R which drives the wormwheel on the horizontal shaft S driving the various feed motions. The gears connecting the central bevel gear with the worm R, can be interchanged as they are placed in the removable guard as shown in fig. 398. This permits of the feeds being doubled once more.

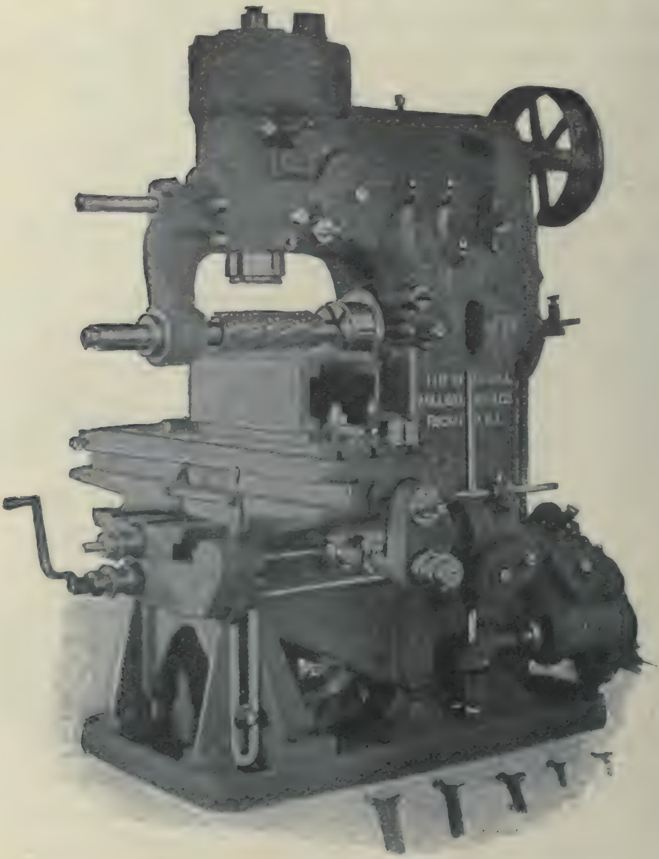


Fig. 400. Ingersoll combined milling machine as a horizontal miller.

The gearing to be seen at the end of the table connects the splined shaft S with the table feed screw and drives the longitudinal feed of the table. At the front of the table is the usual slot in which are the adjustable dogs for the automatic feed stop. The lever V changes the feed gearing at the front of the knee which transmits the automatic transverse and vertical feeds. The ratio of the transverse feed is the same as that of the longitudinal feed, that of the vertical feed being in the ratio of 2 : 1 of the former movements.

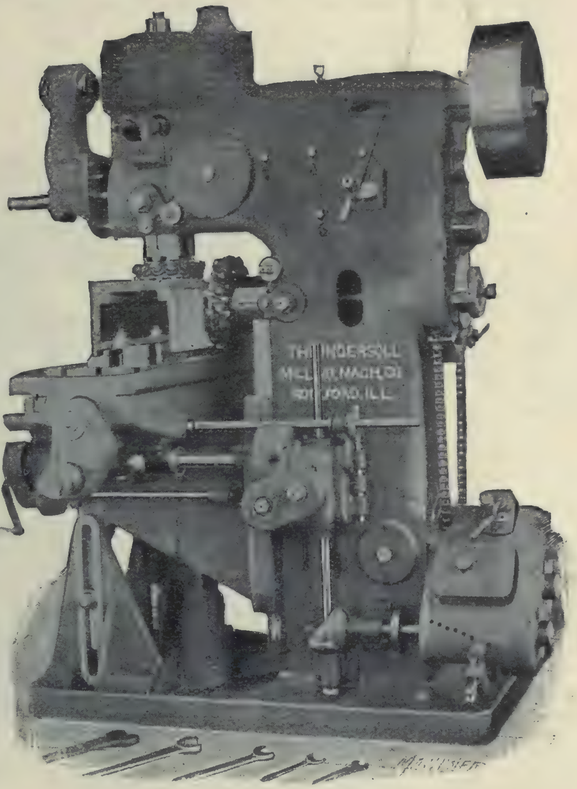


Fig. 401.
Milling with horizontal and vertical spindles simultaneously on an Ingersoll combined milling machine.

The table of this machine has a working surface of 48 × 18 inches with a feed of 56 × 16 inches. The saddle gives a bearing to the table of 60 inches. The knee is 36 inches long, the bearing surface along the column 28 inches, the end being supported by the bracings T. The vertical adjustment is 18 inches. The spindles have an axial adjustment of 6 inches. The greatest distance between the centre of the table and the column is 24 inches, the least distance being 8 inches. The greatest distance from the top of the table to the face of the vertical spindle is 26 inches, the least distance being 2 inches. The greatest distance from the top of the table to the centre of the horizontal spindle is 16 inches, the least distance being zero.

A circular table with a diameter of 16 inches and provided with automatic feed and stops can be mounted on the main table.

Fig. 400 shows the machine working as a horizontal miller, the vertical spindle being disengaged.

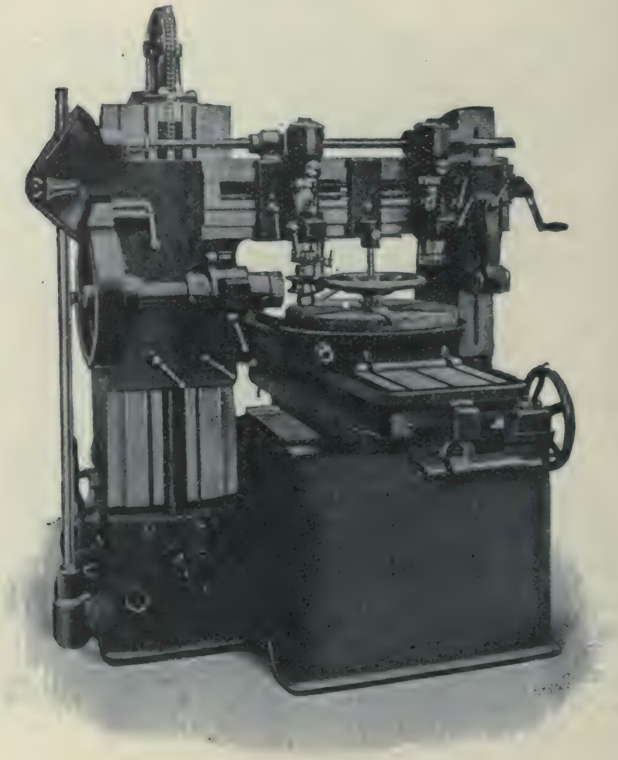


Fig. 402. Combined horizontal vertical and circular milling machine.

In fig. 401 both spindles are at work. When so employed the machine has the same capacity as a horizontal and a vertical machine separately.

Fig. 402 shows a combined milling machine which is a horizontal and at the same time, vertical and circular milling machine of most up-to-date construction and adapted for milling work of great variety.

The square main table, which has a working surface of 48 × 14 inches has longitudinal automatic feed whilst it can be adjusted transversely by hand over the box shaped bed.

A horizontal spindle head traverses the vertical main column, in which head the horizontal main spindle is housed, whilst a cross-rail forming one piece with this head reaches over the table, the end being supported by an additional column. This cross-rail carries two vertical spindles heads both spindles are driven by a worm and worm wheel. This same cross-rail is further provided with outer bearing for the horizontal spindle.

A circular table of 24 inches diameter can be mounted on the main table, provided with automatic rotary feed, thus permitting all rotary milling work coming within the limits of the dimensions of the machine. This machine may be regarded as one of the most useful and handiest of all combined milling machines.

At the present day the horizontal boring and milling machine occupies a leading place among the combined milling machines.

For machining heavy machine parts, for face milling, boring etc., this type of machine has been universally adopted in general machine construction.

Fig. 403 shows such a machine as constructed by the Fosdick Machine Tool Co.

A square table, which can only be adjusted in one direction by hand, is square on the transverse bed, during the milling operation occupying a fixed position, being mounted on the box-shaped bed. On the transverse bed is a vertical column which is adjustable in both directions either by hand or automatically, whilst in addition to automatic feed motion, it has also quick movement over the bed.

A sliding head with automatic and hand feed is mounted on the vertical column. This head carries a spindle bored throughout its entire length and running in bronze bearings.

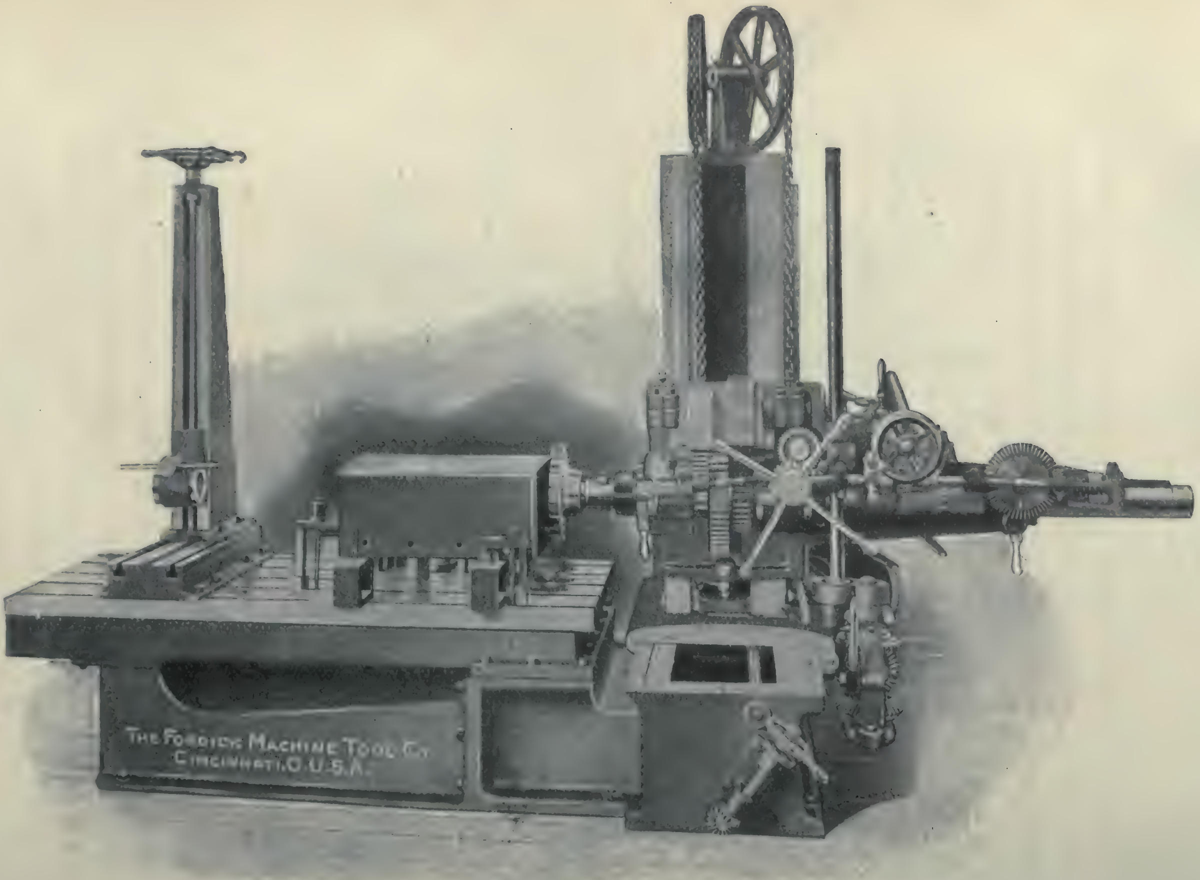


Fig. 403. Horizontal boring and milling machine.

This spindle has a threaded nose which permits of a chuck, large cutter or face cutter being mounted for heavy milling work. This spindle can rotate either to the right or left. A splined boring and milling arbor of 4 inches in diameter can be adjusted longitudinally in the outer spindle, the outer spindle being provided with a key, so that the inside spindle rotates with the outside, though it can be longitudinally adjusted in the latter either by power or by hand in both directions, having also fine adjustment by hand for accurate setting and quick movement for the to and fro motion of this spindle. The end of the spindle is bored to receive a Morse taper N^0. 5 so that drills, cutters and face millers without a threaded bore can be mounted. With 10 different rates of speed, the spindle can make from 4 to 260 revolutions per minute.

Whilst being machined, the work occupies a fixed position on the machine but the spindle can be set at any position as regards the workpiece, either vertically, horizontally or in front, having power feed in either of these directions.

CHAPTER X.

Attachments for the Universal Milling Machine.

A number of attachments are supplied with the universal milling machine which allow of the carrying out of a variety of operations for which the machine was not originally constructed, perhaps, not so rationally and accurately as on a machine specially constructed for the purpose but still, in the absence of such a machine, these attachments which replace it may be used and will certainly prove very serviceable.

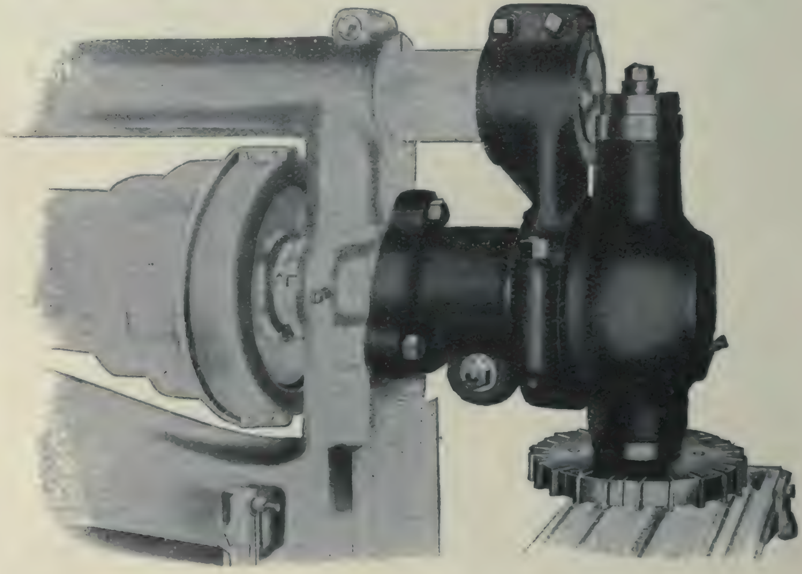


Fig. 404. Vertical spindle milling attachment.

The various attachments which will now be described, must be regarded, notwithstanding their great usefulness, simply as *accessories* and nothing more.

Viewed from this standpoint, they can certainly prove of great service, but to think that by adding such attachments, a universal milling machine can really be changed into a vertical, a circular, a rack milling machine or a slotting machine, is to make a mistake, as practice will prove that the results obtained as well as the handling are not so satisfactory by far as those obtained with a machine specially constructed for one or other of the purposes mentioned above.

One of the attachments most used is the vertical spindle milling attachment, by means of which a vertically rotating cutter can be used on a horizontal milling machine.

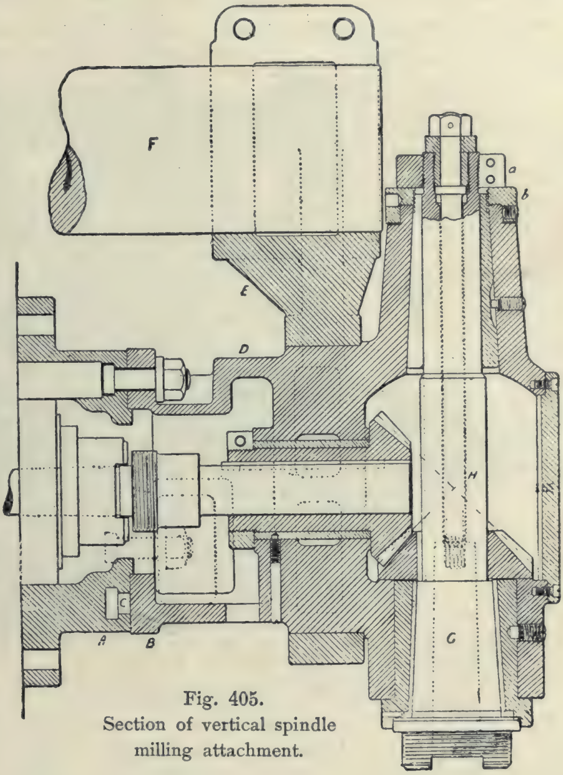


Fig. 405.
Section of vertical spindle milling attachment.

Fig. 404 illustrates a vertical milling attachment whilst fig. 405 gives a sectional view of the construction of such an apparatus.

The attachment is mounted on the machine partly by bolting it to the column and partly by clamping it to the overhanging arm above the horizontal main spindle.

In fig. 405, which differs somewhat in construction from the attachment shown in fig. 404, the part A is bolted to the column. The front of this piece is provided with a circular T slot *c*, in which the attachment, carried by the support E, can be swiveled in a vertical plane through 360 degrees, thus permitting of the attachment being set at any desired angle.

A shaft, clamped in the horizontal main spindle, drives the vertical spindle by bevel gearing when it rotates.

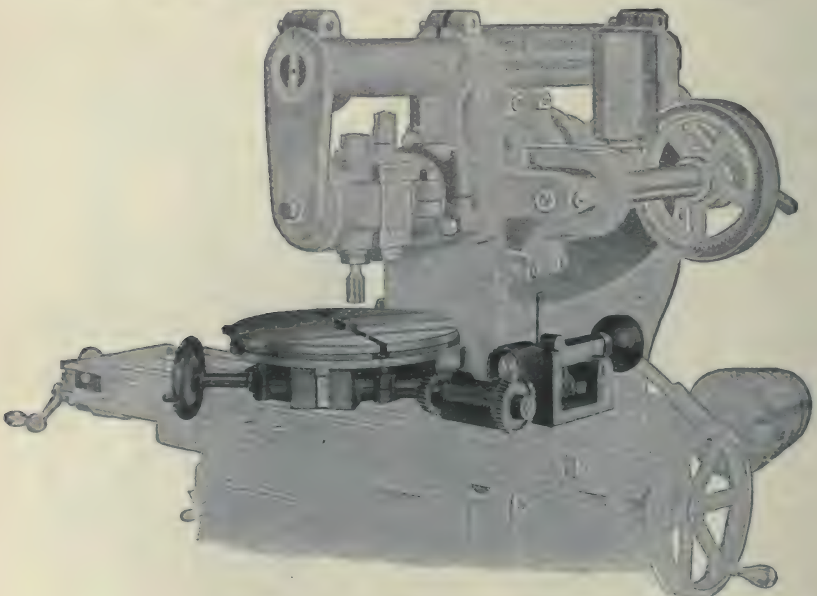


Fig. 406. Circular table on horizontal milling machine.

The journal G runs in a bronze taper bearing, adjustable by the nut *a*. The top bearing, which is tapered on the outside and cylindrical internally, is split throughout its entire length, being adjustable by the nut *b*, thus narrowing the internal diameter.

The taper bore in the vertical spindle is the same as in the horizontal main spindle so that the same cutters and arbors can be used. The vertical spindle is bored throughout its entire length, and in this bore is enclosed the draw bolt H by which the cutters and arbors, which are provided with a

$^5/_8$ inch threaded hole at the top, can be drawn in or pushed out. The spindle nose is threaded so as to permit of mounting face millers.

A circular table is an almost indispensible adjunt to the vertical milling attachment as its use permits of rotary milling being performed on a horizontal milling machine. Such a circular table is illustrated in fig. 406 and is mounted on the main table of the machine. The telescopic shaft which transmits the feed motion to the main table, is changed and attached to this circular milling table so that the latter can be made to rotate automatically and by hand, whilst it has the same number of feeds as can be imparted to the main table.

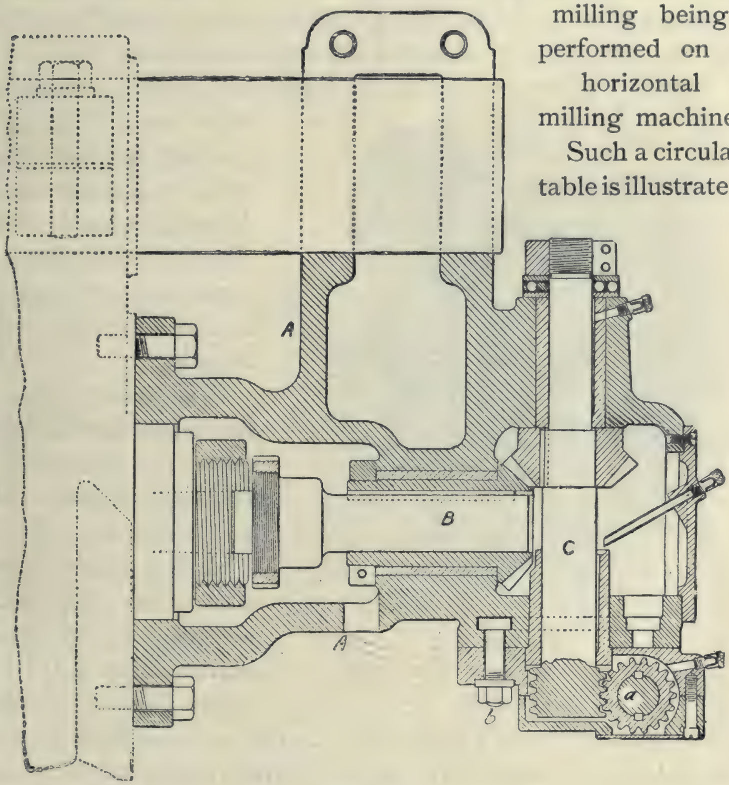


Fig. 407.
Attachment for milling wide angle spirals on a universal milling machine.

The vertical spindle milling attachment mounted on the machine in fig. 406 is of a different construction to either of those shown in figs. 404 or 405. Such attachments are manufactured in a variety of constructions.

For milling spiral gears and wide angle spirals which do not permit of being cut on the universal milling machine, a spiral milling attachment, a sectional view of which is given in fig. 407, can be mounted on the machine.

Spirals of any angle can be milled with this attachment, right as well as left-handed, as also racks, which must be mounted *lengthwise* on the table, the arbor thus rotating parallel to instead of square on the main spindle.

The casting A of this attachment is bolted to the column, being further clamped to the overhanging arm.

Shaft B which rotates with the horizontal main spindle, drives the vertical spindle C by a bevel gearing, the end of spindle C being formed as a spiral wheel which meshes another spiral wheel mounted on the horizontal shaft *a*. The ratio between these spiral wheels is 2 : 1, so that the horizontal main spindle makes twice as many revolutions as the horizontal spindle of the attachment, which gives a far greater belt pull. The end thrust of the vertical as well as of the horizontal spindle is taken up by a ball bearing.

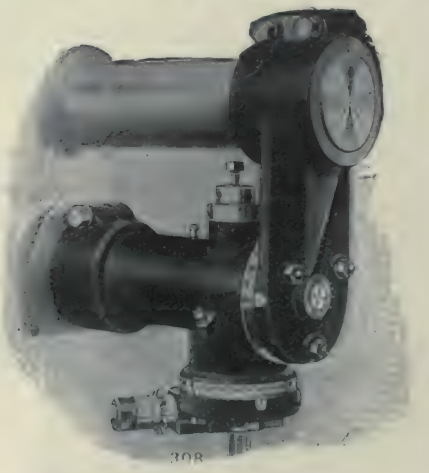


Fig. 408.
Universal milling attachment.

A similar attachment, unsuited however for heavy milling work, but more generally adopted than that shown in fig. 407, is illustrated in fig. 408. This attachment is equally well suited for vertical milling as for milling wide angle spirals and racks and is applicable to a large variety of work.

The vertical spindle of this attachment can be set at any angle in the vertical plane so that even slanting sides can be milled; if the vertical spindle be swiveled 90 degrees from the vertical position, a horizontal cutting spindle will result, though square to the horizontal main spindle. As previously mentioned, spiral gears and spirals with a greater angle than 45 degrees can be milled with the horizontal spindle of this attachment, and seeing that this spindle can be turned to any angle in the horizontal plane, a large number of different positions can be obtained so that by using either a shell end mill or an end mill, a great variety of milling work which would otherwise be very difficult ot perform on a universal milling machine, can easily be carried out.

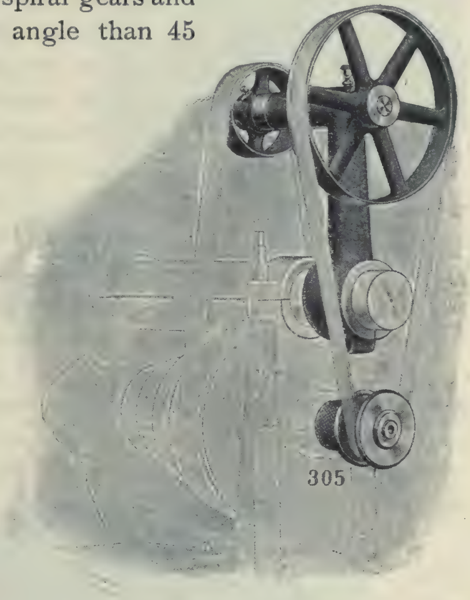


Fig. 409.
High speed milling attachment.

Whenever a cutter of exceptionally small diameter or a small drill is used on a universal milling machine, the main spindle of the machine, even at its highest speed, rotates far too slowly. For this reason the majority of manufacturers of universal milling machines supply an attachment which enables a small cutter or drill to rotate at a very high speed.

Fig. 409 shows such an attachment and the increase of speed obtainable can easily be seen. From the cone pulley increased speed is imparted to a horizontal shaft above the overhanging arm, from whence motion is transmitted at an increased rate to the small pulley mounted in front of the main spindle of the machine by means of a larger pulley. The small pulley runs on a bronze stud which fits in the main spindle, and has a conical bore which enables the small cutter to be fitted. In this manner the small cutter can be made to rotate at from 1500 to 1800 revolutions per minute.

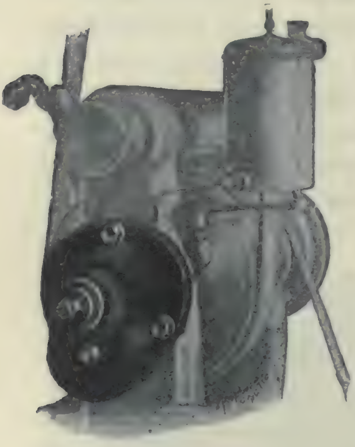


Fig. 410.
High speed milling attachment.

A simpler attachment for the same purpose is that shown in fig. 410. This attachment is bolted to the column, the high speed spindle being driven by gearing. The same number

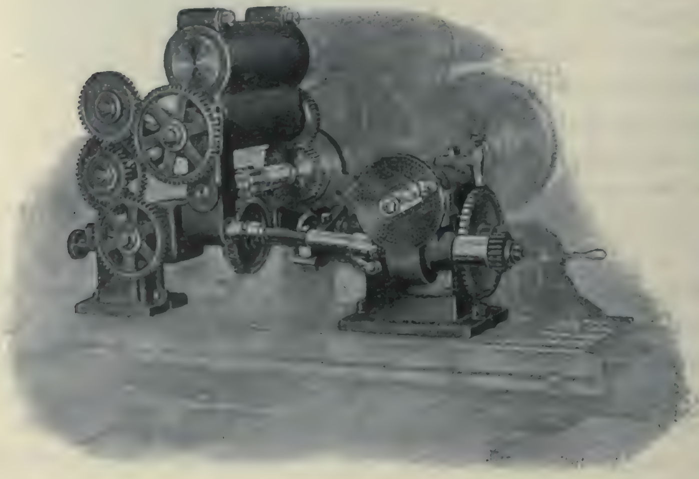


Fig. 411. Spiral and worm wheel hobbing attachment.

of speeds at which the main spindle can rotate can also be imparted at an increased ratio to the high speed spindle.

An attachment for the hobbing of worm wheels is shown in fig. 411. It is used in connection with a plain dividing head. A hob is fitted in the main spindle. The attachment is clamped to the overhanging arm and driven by a gear that is attached to the main spindle nose. Motion is transmitted to the telescopic shaft by gearing. The telescopic shaft in its turn causes the spindle of the dividing head which drives the worm wheel blank, to rotate through the worm and worm wheel of the head.

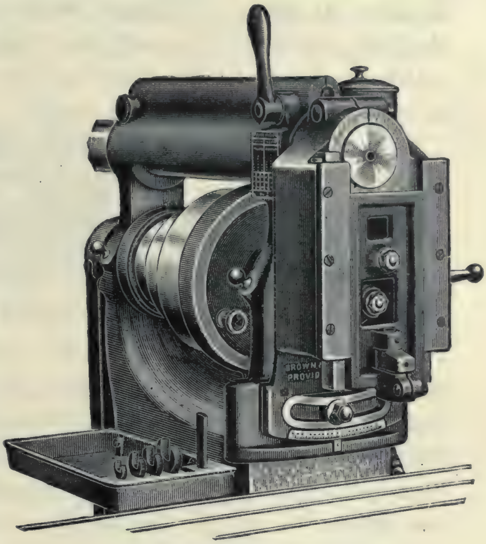


Fig. 412. Slotting attachment.

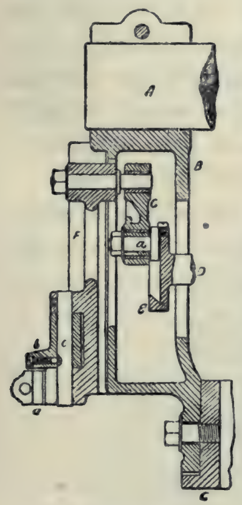


Fig. 413.
Sectional view of slotting attachment.

The consequence is that there is a fixed ratio between the number of revolutions of the hob and the worm wheel blank, the number of teeth of the latter being dependent on this ratio. By changing the gears between the driving shaft and the bevel gearing, all worm wheels up to 50 teeth, all even numbers between 50 and 100 and many odd numbers between 100 and 360 can be cut.

Fig. 412 shows an attachment by means of which the rotary movement of the main spindle is changed into a vertical up and down motion, thus converting the milling machine into a small slotting machine. This attachment is unsuited for ordinary slotting work, but is used for tool making of all kinds, such as box tools, templates etc.

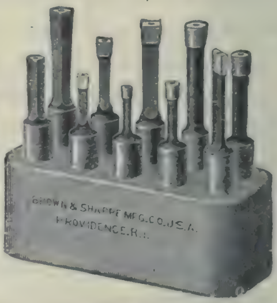


Fig. 414.
Slotting tools.

Fig. 413 gives a sectional view of this attachment. It is clamped to the overhanging arm A above the spindle and bolted to the column by a bolt in the circular slot. The attachment can thus be swiveled 10 degrees from the vertical on either side of thecentre of arm A.

A crank disc is fitted in the horizontal main spindle, which is partly shown at D. In this disc is a dovetailed slot in which is placed the crankpin *a* by means of which the stroke is adjusted. This crankpin moves the crank G and the slide F up and down. The tools used with this attachment differ in form from the ordinary slotting tools. A set of tools for use with this attachment is shown in fig. 414.

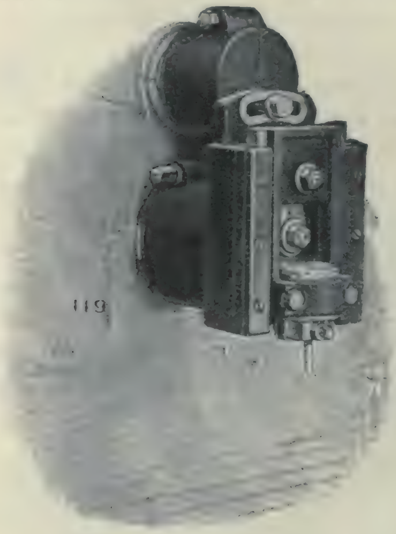


Fig. 415. Slotting attachment.

Fig. 415 shows a similar attachment with this difference, however, that the tool can be swiveled in a complete circle and can thus be set in any desired positon.

For milling a number of pieces of similar shape simultaneously, a triple index centre head, i. e. one provided with a number of centres, can be mounted on the table of the milling machine instead of the usual dividing head.

Fig. 416 illustrates such an attachment. With this attachment three workpieces can be taken between the centres and milled simultaneously, all of which turn at the same time by moving the crank handle of the dividing head. This attachment can be used advantageously for a number of operations, as for instance, for milling quadrants or hexagons on spindles, for cutting small pinions which form one whole with the shaft and must consequently be milled tooth for tooth, which would otherwise take up considerable time in grooving taps etc.

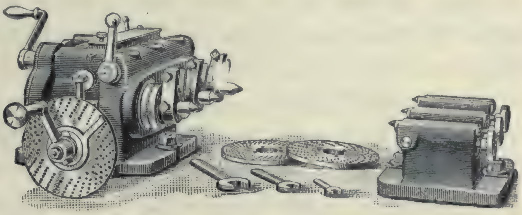


Fig. 416. Triple index centres.

Fig. 417 shows a special attachment for milling racks on the universal milling machine. The attachment is fixed to the column, one or two racks being put in a special jig. In connection with this attachment, a quadrant is mounted on the table feed screw for the exact adjustment of the table necessary for rack teeth cutting. This quadrant,

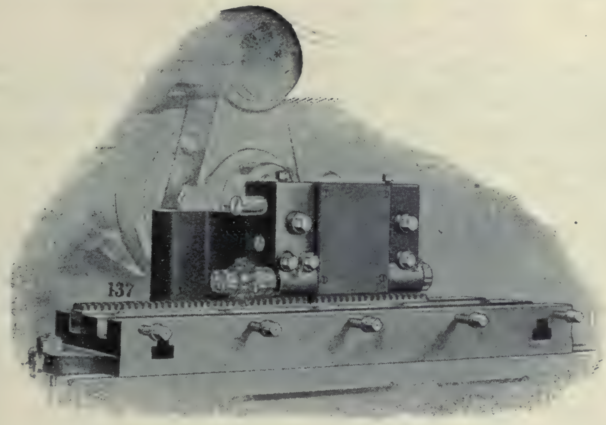


Fig. 417. Attachment for rack milling.

(fig. 418), is provided with a disc in which are two notches in which a pawl presses.

A spur gear is mounted on the table feed screw that meshes another spur gear fixed to the notched disc and the ratio of these two gears can be determined in such a manner that the disc must make exactly one half or a complete turn for the table motion equal to the pitch of the rack. The disc has only two notches. If the disc has only to make half a revolution when turning the crank handle on the table feed screw, the pawl is drawn out by hand from the notch into which it has been pressed by a spring and when the disc is turned half a revolution, it engages the next notch. In order to prevent mistakes when the disc has to make a complete revolution, one of the notches is filled up.

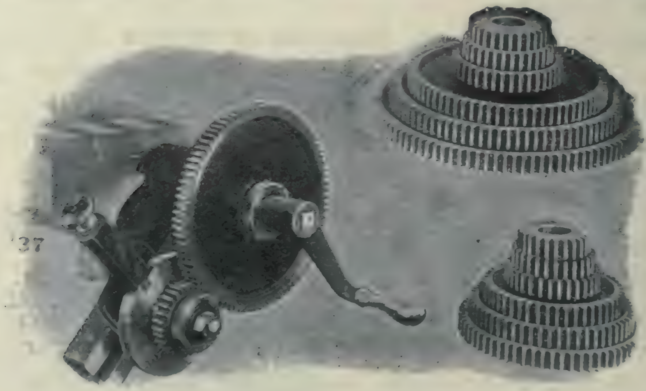


Fig. 418. Dividing attachment for rack milling.

Fig. 419 shows a tailstock that is used for supporting the outer end of taper work when the angle is large or the work long. The centre of this tailstock can not only be placed considerably higher than the centre of the dividing head but, and this is the chief advantage of this attachment, the centre can be placed at an angle suitable for the workpiece, thus preventing any side strain on the centre. The angle at which the workpiece is placed can be seen from the dividing head, whilst the swivel block of the tailstock is also graduated in degrees which permits of both being placed at the same angle.

Fig. 420 shows an attachment supplied by the Cincinnati Machine Tool Co. by means of which spur gears of large diameter can be milled on the universal milling machine. The ordinary manner of working on the milling machine is that the cutter mills either on top or side of the workpiece. In the case of spur gears, it mills above the workpiece. When such is the case, however, no spur gears can be milled which have a diameter larger than the maximum distance between the top of the table and the centre of the main spindle of the milling machine, from which must be deducted half the diameter of the cutter and a certain amount of play.

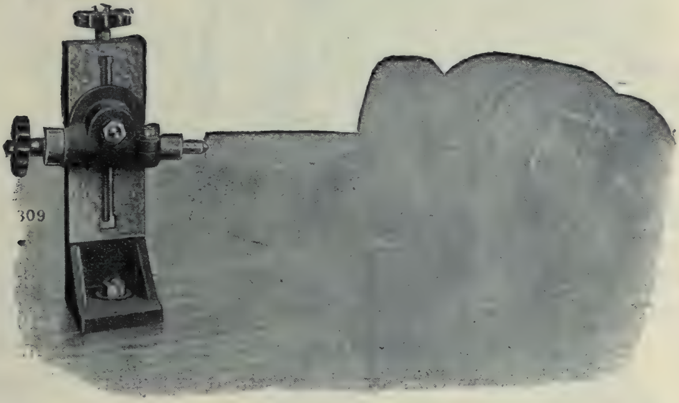


Fig. 419. Universal high tailstock.

As a matter of fact, however, no spur gears can be milled when their diameter exceeds double the height of centres of the universal dividing head. For the No. 1 Cincinnati milling machine this is 10 inches and for the No. 4 14 inches. With the attachment shown in fig. 420, spur gears can be milled on the No. 1 machine up to 20 inches and on the No. 4 machine up to 26 inches in diameter, thus, practically twice the former diameters. The attachment consists of two

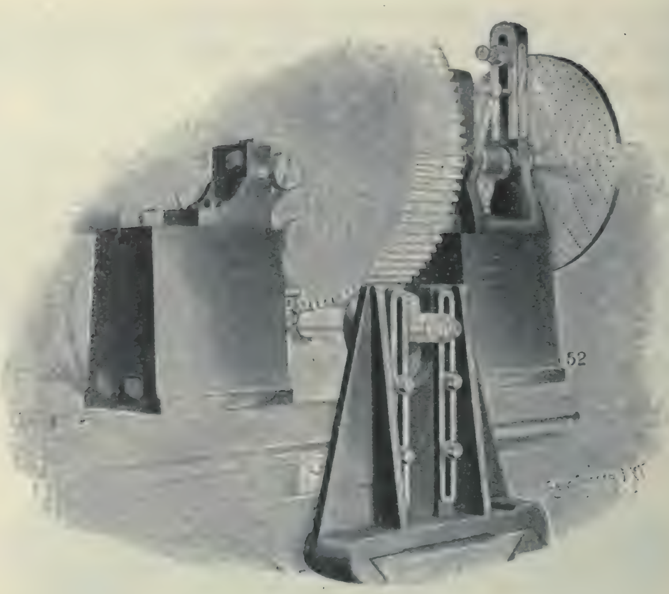


Fig. 420. Undercutting attachment.

raising blocks on which the dividing head and tailstock are mounted, the arbor being carried in a special outer support. The spur gear blank is supported immediately above the cut by an adjustable stud in the raising block under the tail-

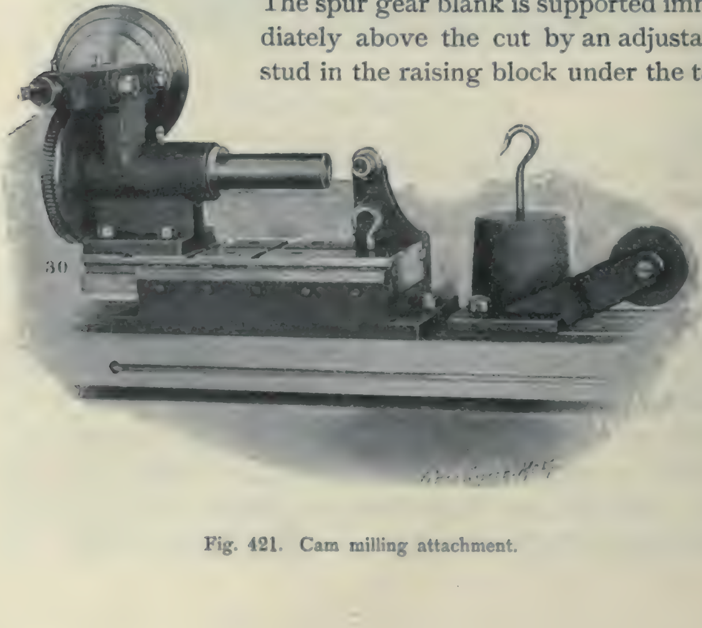


Fig. 421. Cam milling attachment.

stock, which takes the strain due to the thrust of the cutter and thus relieves the tailstock and prevents any buckling of the spur gear. It will be clearly seen from the illustration that the cutter now works *under* the workpiece.

Fig. 421 shows an attachment for milling cams and other objects of irregular shape not only on the circumference but also on their flat surfaces. By means of the weight shown on the table that is attached to a steel wire which is fixed to the hook in the slide of this attachment, the slide is pushed against the former, the shape of which it consequently follows.

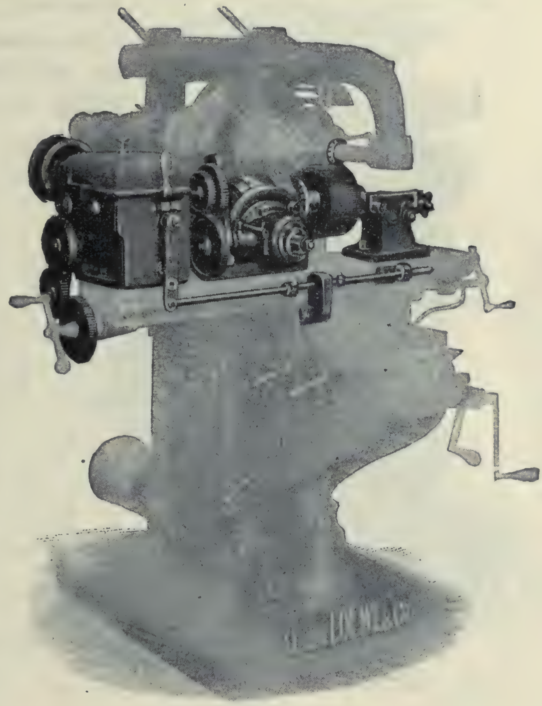


Fig. 422.
Full automatic milling of gear wheels on a universal milling machine.

Gear wheels can be cut on the universal milling machine but semi-automatically, that is to say, for each tooth space the table must be returned by hand; the dividing head spindle must be turned by hand one tooth farther on, after which the machine can recommence its work automatically until the tooth space is cut, when the machine must again be attended to.

On this account, when cutting gear wheels the machine requires almost uninterrupted attention. There are, as described before, various gear cutting machines on the market which work fully automatically, but in so many shops the purchase of a special gear milling machine would not pay. A very ingenious attachment manufactured by Loewe, by which the universal milling machine is transformed into an fully automatic gear cutting machine, deserves attention. The attachment can be used on any universal milling machine, works in combination with the universal dividing head, and is equally suited for milling either spur or bevel gears. Fig. 422 shows the attachment cutting spur gears, fig. 423, an angle cutter.

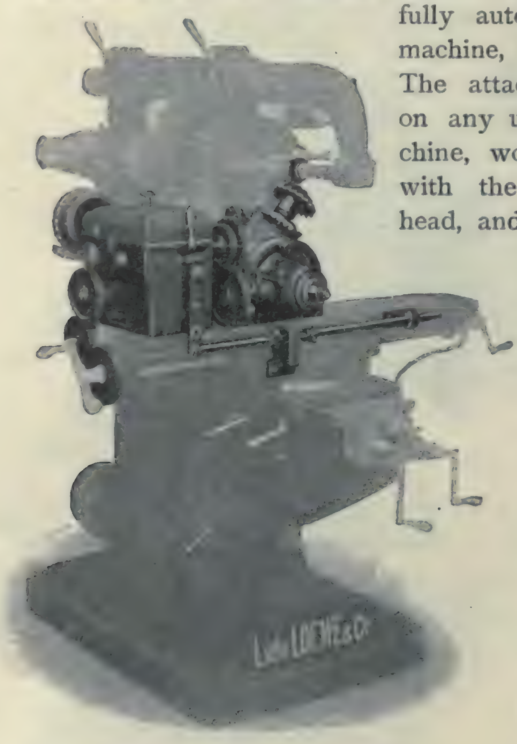
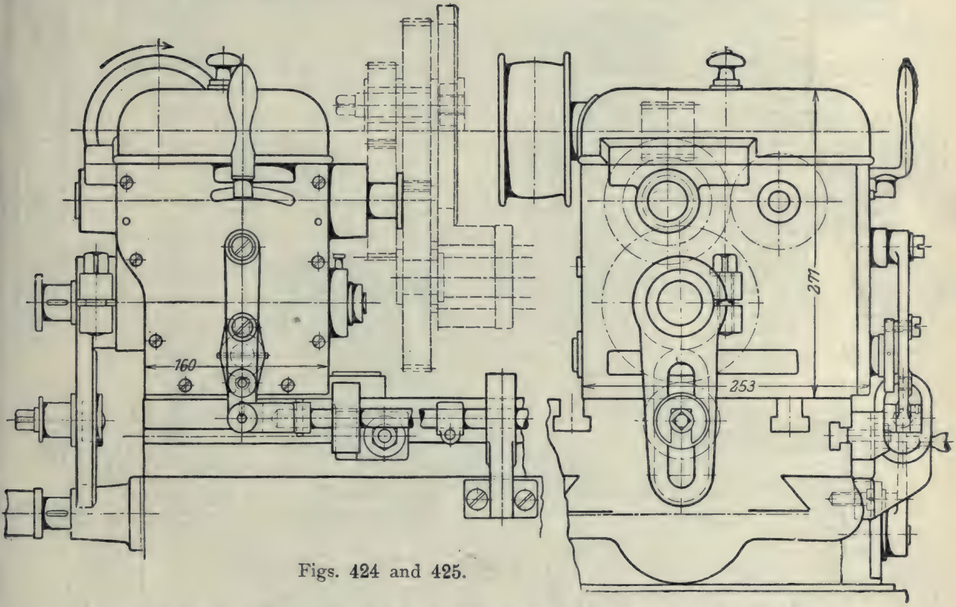


Fig. 423.
Full automatic cutting of an angle cutter on the universal milling machine.

The external form of this attachment is a closed gear box (figs. 424 and 425), mounted on the end of the table, at the rear of the dividing head which is now placed more to the centre of the table. The change gears otherwise employed for spiral milling and which connect the dividing head and the feed screw, are now used for the automatic travel of the table and its quick return, the change gears on the dividing head being used for the automatic dividing motion of the latter.

The manner in which the attachment works is shown in figs. 424—425, and is as follows:—

The drive takes place by means of a pulley *a*. Shaft *b* has motion imparted to it by a worm and worm wheel. By means of gearing a right or left-hand motion is imparted by shaft *b* to shaft *c* after engaging the clutch *d* either on the right or left hand. Shaft *b* also causes shaft *f* to rotate to the right by gearing. By change gears mounted on the stud *e* of shaft *c* motion is brought to the table *g* of shaft *f* controlling the dividing motion. The dividing motion thus depends on the movement of the table, the latter acting on the dividing head by the lever *h* which is bound to the draw-rod in front of the table, for the reverse movement (see figs. 422 and 423). The speed of the return, stroke which is now entirely automatic, is increased eightfold. Fig. 429 shows the mechanism of the attachment with the cover removed.

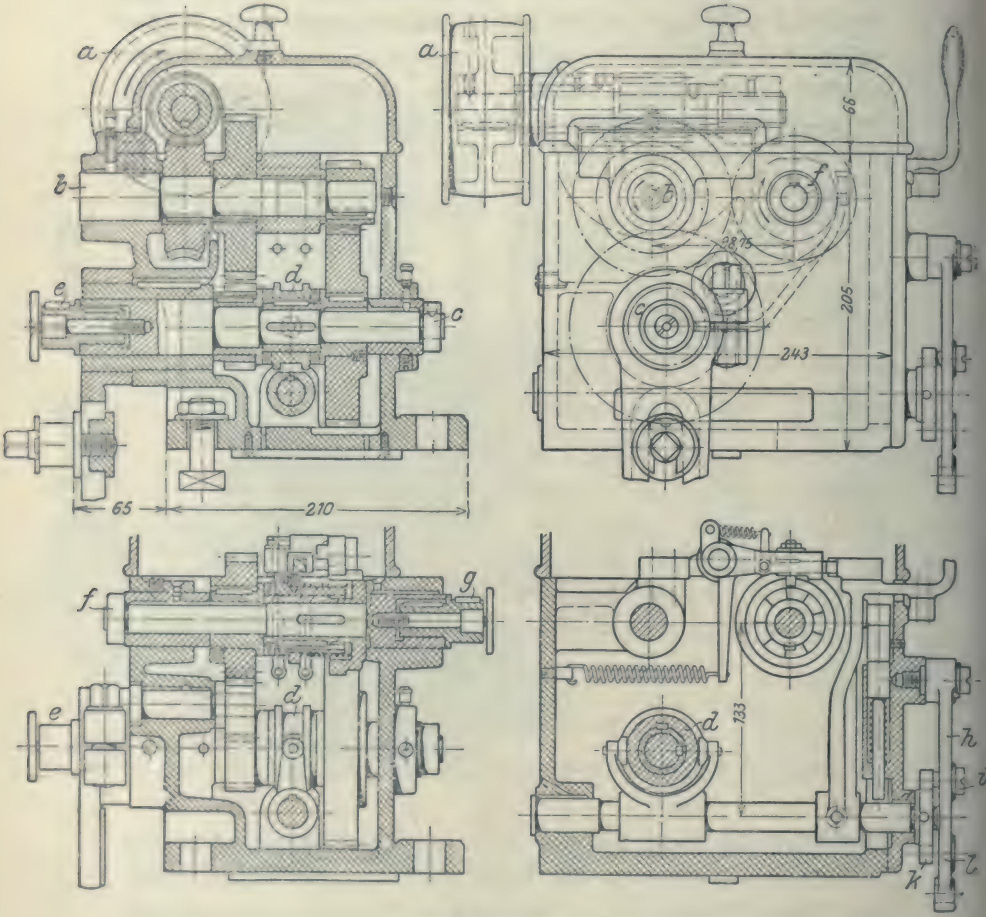


Figs. 424 and 425.

Attachment for milling gear wheels automatically on the horizontal milling machine.

Pulley *a* is driven by a belt running either from the countershaft, in which case it runs over the guide pulleys shown in fig. 430, or by an electromotor which can be attached underneath the table of the milling machine (figs. 431 and

432), though this can only be done when the table is sufficiently strong. The stops to be seen on the horizontal rod in figs. 422 and 423 serve to limit the automatic longitudinal travel of the table as they come in contact during the travel of the table with one of the stops on the saddle.



Figs. 426—429.
Sectional views of the attachment for milling gear wheels automatically on the horizontal milling machine.

This rod is connected to the lever *h* (fig. 429), which is connected with the reversing lever *k* by screw *i*. By shifting the screw *i* to *l*, the to and fro motion can be reversed.

The automatic dividing after the return of the table is accomplished in such a manner that the shaft *f* on which the driving gear is mounted, completes exactly one revolution for each division. This must be taken into account when calculating the gear wheels for a certain number of divisions in addition to the ratio of gearing on the dividing head.

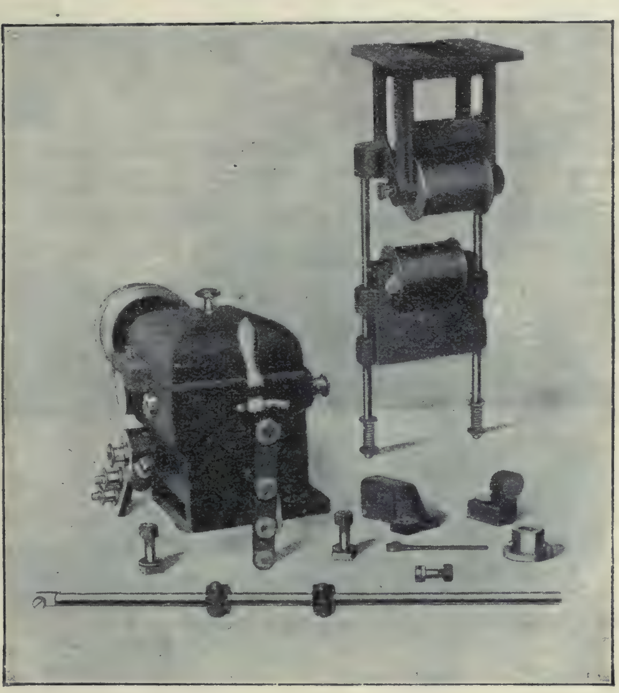
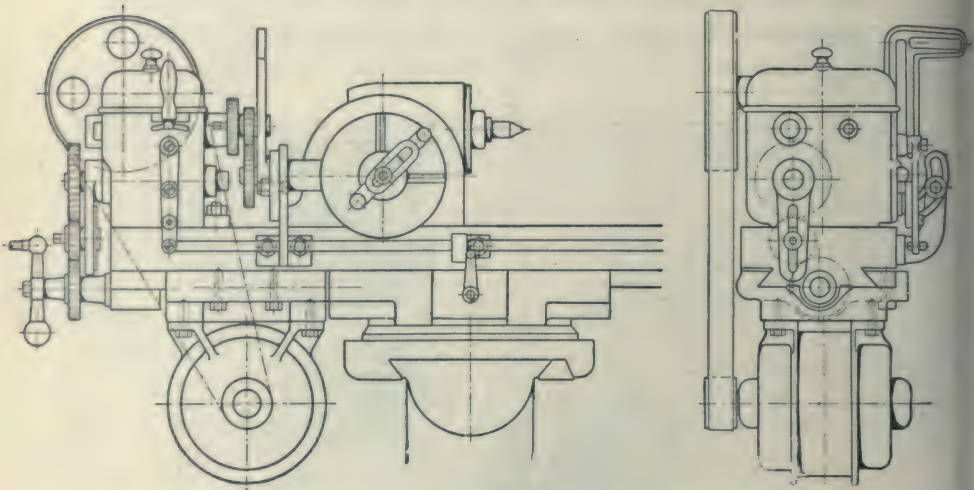


Fig. 430. Belt guide apparatus.

Universal milling machines provided with this attachment are metamorphosed into fully automatic gear cutting machines, whilst bevel gears and angle cutters can also be cut since the dividing head can be placed either vertically or horizontally or at any intermediate angle.

In addition to the attachments for general use just mentioned, a number of more special attachments are supplied with the universal milling machine with the sole object of making this type of milling machine really and truly universal. As has already been said, the value of these attachments must not be estimated higher than it really is; in certain cases they are of excellent service, being really invaluable, for which reason the universal milling machine cannot yet be regarded as suited for every purpose, since each special kind of work can be much better performed on a machine specially constructed for the purpose.



Figs. 431 and 432. Electric drive of attachment shown in fig. 422—423.

CHAPTER XI.

Clamps and Clampings Devices.

Clamping devices may be divided into two main groups:—

1. General clamping devices.
2. Special clamping devices.

A workpiece to be machined on the milling machine must be firmly fixed to the machine for that purpose. The manner in which this shall be accomplished depends entirely on the dimensions and form of the workpiece.

If a certain kind of work has to be turned out in large quantities or the same class of work is constantly recurring, it pays to make special clamping devices specially adapted for pinching such workpieces as quickly and expeditiously as possible in accordance with their shape.

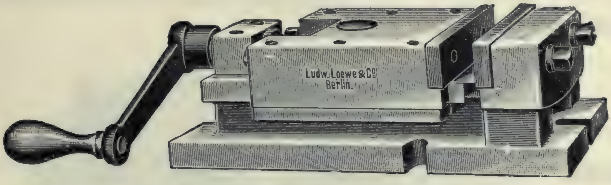


Fig. 433. Plain parallel vise.

But milling work is not always repetition work so that it is necessary to have certain appliances at hand for clamping work of diverse form and dimensions to the machine.

One of the appliances most generally in use is the parallel vise, which at the present time almost invariably forms part of the equipment of the machine.

Such a parallel vise is illustrated in fig. 433. The vise itself has a baseplate by which it can be easily attached to the table, the workpiece being held between the jaws. A possible difficulty in connection herewith is that when the vise is set in a central position on the table, the crankhandle for turning the screw which moves the moveable jaw, cannot make a complete turn.

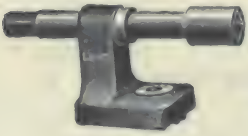


Fig. 434.
Extension piece.

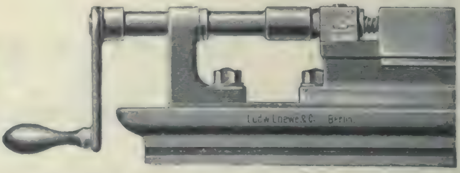


Fig. 435.
Parallel vise with extension piece.

For a single occasion this is not so serious, though when used continuously it will cause considerable loss of time. Fig. 434 shows an accessory which can also be mounted on the table. One end of the horizontal arbor is formed as a socket and fits the square part of the screw of the parallel vise, the crankhandle fits on the other end which now projects beyond the table, (fig. 435), and can thus make a complete turn.

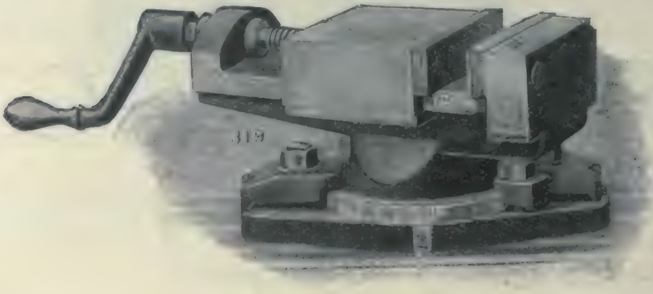


Fig. 436. Swivel vise.

The vise shown in fig. 433, is what is called a plain vise, in contradiction to that shown in fig. 436, the base of which is clamped to the table and whilst this part remains fixed, the upper part can, with the workpiece, be swiveled to any desired angle in the horizontal plane so that it is possible to mill surfaces which are not parallel to the sides of the workpiece, as shown, for instance, in fig. 438.

The vise shown in fig. 436 can only swivel in the horizontal plane. Fig. 437 shows a vise that can also swivel in the vertical plane and although not in a complete circle, still from horizontal to vertical, i. e. 90 degrees, so that the workpiece can be set at any position within the limits of this space. Only moderate size workpieces can be clamped in these vises. Fig. 439 shows a vise of considerably heavier construction, also of the swivel type.

The vises illustrated above have the great disadvantage that they can only clamp workpieces with equidistant sides so that rough pieces which do not comply sufficiently with this condition, cannot be clamped harmly enough to allow of the surfaces being accurately tooled. A vise is illustrated in fig. 440 which has one fast jaw whilst the other can be swiveled and as it can be set at any desired position, workpieces of very irregular shape can easily be clamped. It should be noted that in the case of the vises illustrated in figs. 439 and 440, the loose jaw is not threaded but the workpiece is pinched by the pressure of a bolt. Besides the internal thread in the loose jaw is quickly worn out, when the screw is bended the jaw can only be moved with difficulty unless the jaw is permitted to follow the swinging motion of the screw by giving it play in

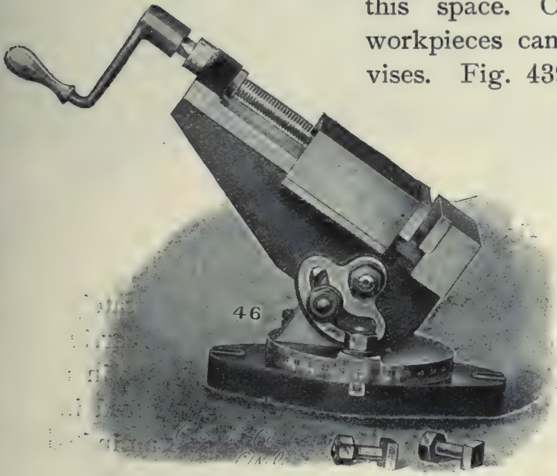


Fig. 437. Universal vise.

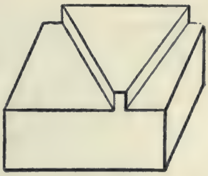


Fig. 438.

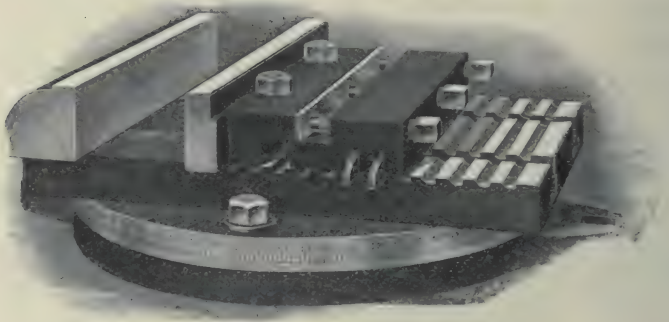


Fig. 439. Swivel vise.

the vise but then the workpiece is not clamped accurately, since when clamping, the loose jaw is lifted and carries the workpiece with it so that when pinched, it is not in a true position. For this reason vises are to be preferred in which the jaw pinches the workpiece by means of an independent pressure bolt which has no fixed connection with the loose jaw.

Fig. 441 shows a vise, the loose jaw of which can be swiveled in any position and which pinches the workpiece because the bolt on the back of the jaw is placed at an angle with regard to the surface over which the jaw moves

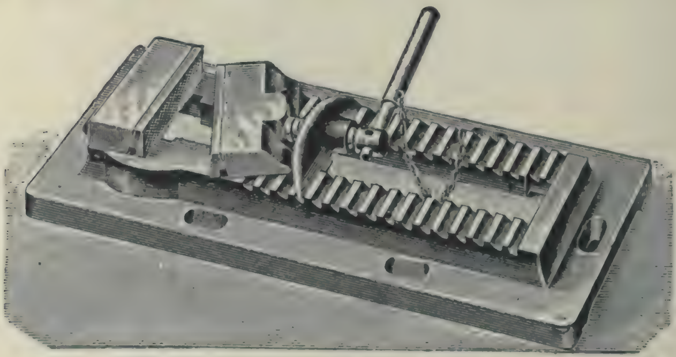


Fig. 440. Quick setting vise with swiveling jaw.

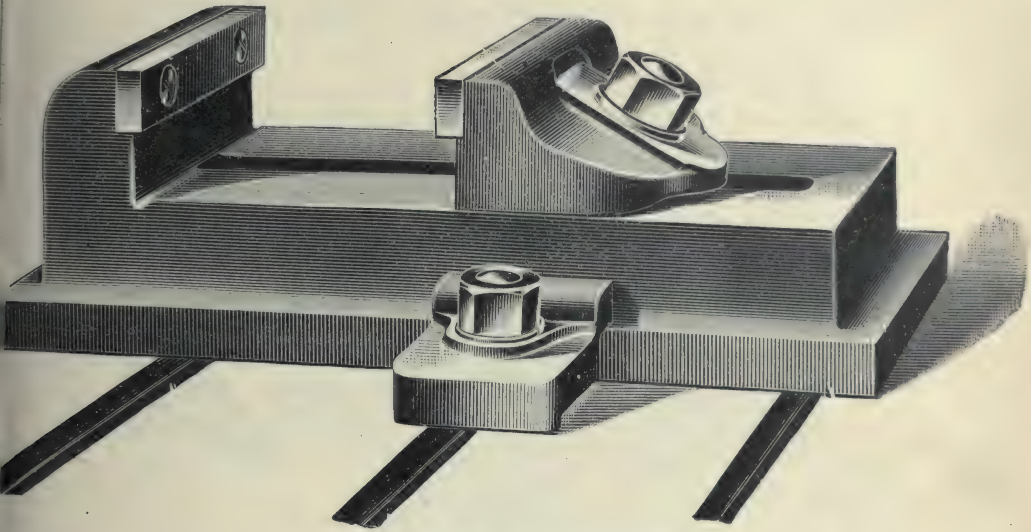


Fig. 441. Vise with independent jaw.

so that the latter is drawn towards the fixed jaw by fastening the bolt.

This vise offers still another advantage in that the jaw can be completely reversed so that by a combination of two vises, workpieces can be clamped which are of considerably greater length than could be placed between the jaws of one vise as shown in fig. 442.

Next to the vise as general clamping device comes the angle plate, as illustrated in fig. 443, for objects which have to be clamped to a vertical surface, the use of which is generally known. For workpieces which require to be set at an angle or have to be placed in various positions in a vertical plane without resetting, the angle plates as shown in fig. 444

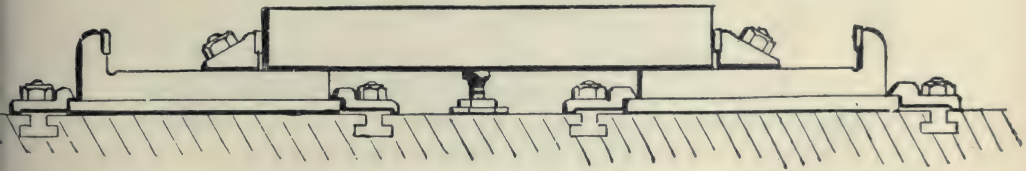


Fig. 442. Combination of two vises shown in fig. 441.

and 445 are used, the vertical surface of which can be set at an angle.

Fig. 446 shows a very simple vise for use when milling keyways in shafts. With this vise the upper portion of the shaft is quite free.

Those parts, which on account of their shape or dimensions, cannot be clamped in a vise, must either be clamped to the table direct by means of bolts and plates or clamped in jigs specially made for the purpose.

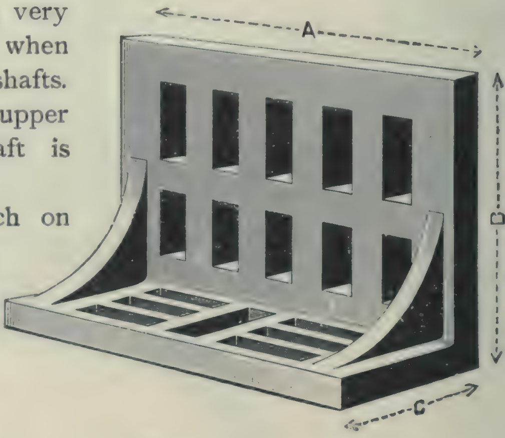


Fig. 443. Angle plate.

The simplest case of all is when the workpiece has a number of projecting parts which are lower than the surface to be milled so that it can be bolted to the milling table by clamping plates and bolts, (fig. 447).

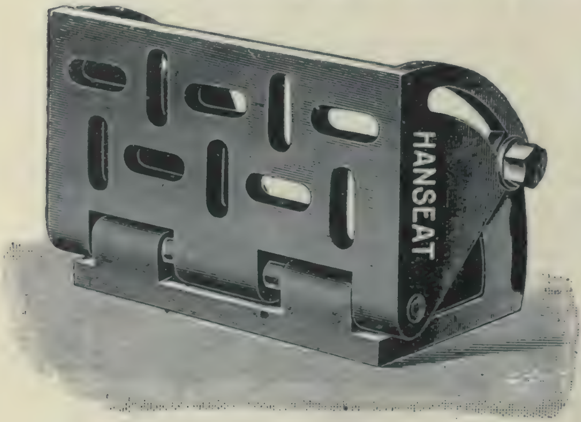


Fig. 444. Swivable angle plate.

If, however, the form of the workpiece is such that clamping with plates would cover a portion of the surface to be machined, another method of clamping must be chosen. This is effected as shown in fig. 448 and 449, but clamping in this way cannot by any means be regarded as at all atisfactory. The workpiece is insufficiently pressed on the milling table so that there is no certainty that perfect parallel surfaced pieces will be obtained whilst there is also a possibility of its working loose during the tooling process.

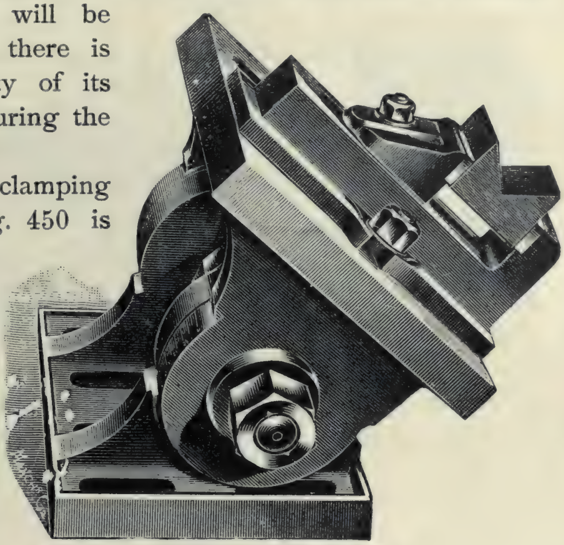


Fig. 445. Swivable angle plate.

The manner of clamping illustrated in fig. 450 is better adapted to press the workpiece down properly although it is, however, also primitive since such a combination of clamping strips is only really suitable for one particular piece of work, as other strips would have to be selected for work which varies in width, and as the operator is in such cases accustomed to look for

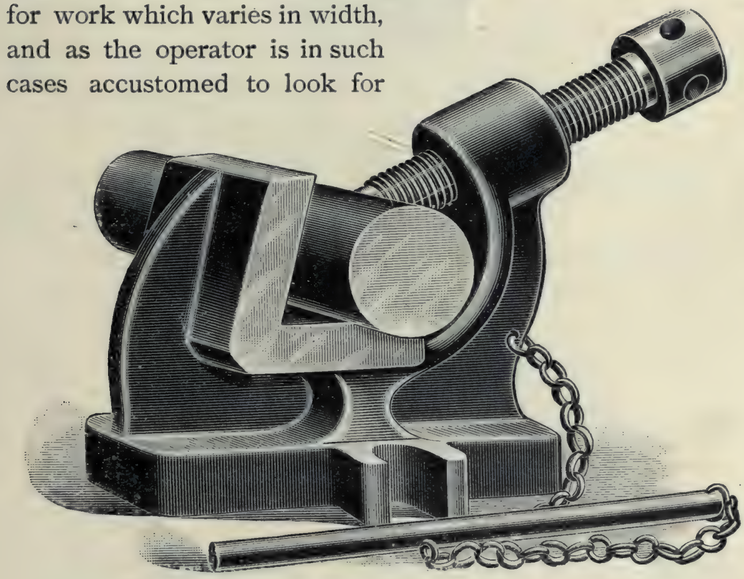


Fig. 446. Shafts vise.

strips at hand, the exact proportions usually leave much to be desired.

The Ingham clamp shown in fig. 451 is a decided improvement on the last-named manner of clamping. The stud on which the jaw swivels is at an uneven distance from the four sides so that this clamping device is suited for workpieces of various height or width. An equally serviceable clamp to that shown in fig. 451 is the Newark combination clamp, (fig. 452), which clamps the workpiece very firmly.

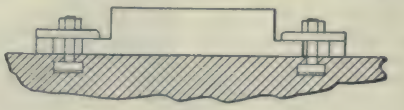


Fig. 447. Clamping plates.

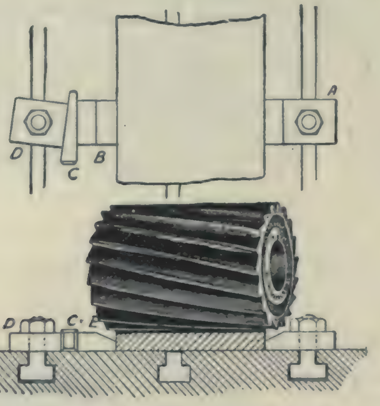


Fig. 448 and 449. Clamping strips.

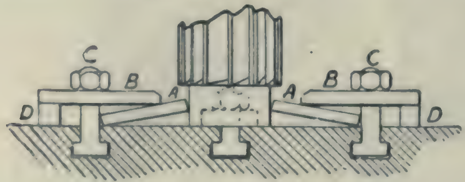


Fig. 450. Clamping strips.

Small and very thin workpieces, the whole upper surfaces of which have to be machined, can only be clamped with the greatest difficulty either in a vise or by means of clamping strips. In such cases, magnetic chucks similar to the one shown in fig. 453, have to be employed. Such workpieces as a rule require to have very little of the material taken off. The work is, therefore, usually done with an end mill.

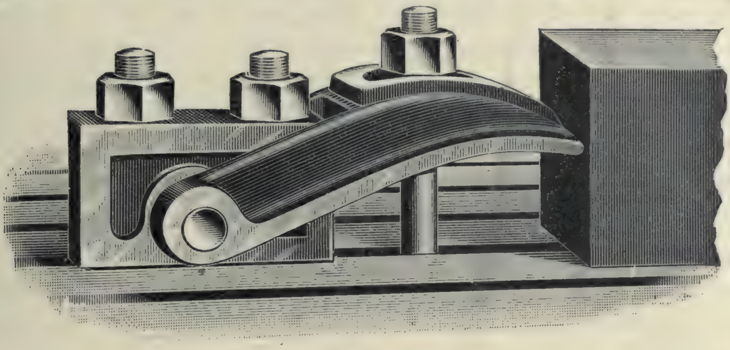


Fig. 451. The Ingham clamp.

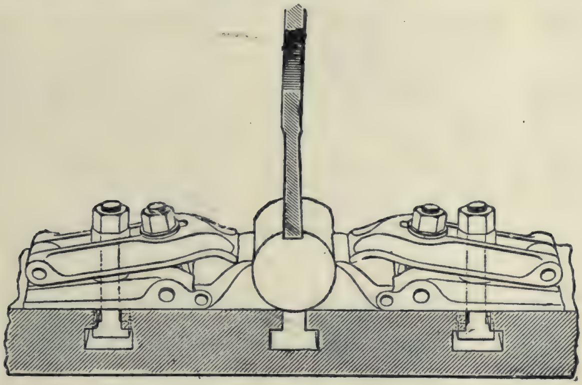


Fig. 452. The Newark combination clamps.

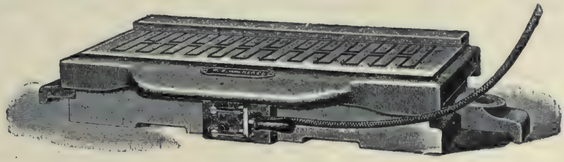


Fig. 453. Magnetic chuck.

In addition to all these clamping devices which are of a more general character, a large number of special devices and jigs are employed for clamping workpieces on the milling machine, which cannot even be reviewed generally as they are usually constructed according to the form of the workpiece and the special nature of the work to be performed.

A clamping device not belonging to the general category of vices and, at the same time, adapted for various classes of work, is deserving of special notice.

It so frequently happens, especially with the vertical milling machine, that work, having a bore, has to be milled either wholly or partially in a circular form, as for instance, the heads of connecting rods, levers, cranks etc. In such cases of bossing, the ends the workpiece must rotate on the centre of the bore.

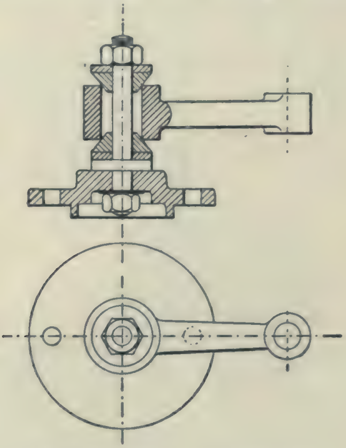


Fig. 454—455. Cone mandrel.

Figs. 454—455 show a cone mandrel which, when mounted on the circular milling table, clamps the workpiece quickly, firmly and truly, whilst, when once the centre of the spindle of this clamping device has been set accurately in the centre of the milling table, the workpiece is bossed perfectly true.

CHAPTER XII.

The Power absorbtion of the milling machine.

It will certainly not have escaped the notice of the reader that as far as possible theoretical considerations have been avoided. This has chiefly been done to prevent the purpose of the present work, viz:—the popularising of the milling machine and the promotion of milling practice, from being lost sight of.

This consideration is the reason why in the following chapters in which the practical part of milling comes even more to the front than in those which have preceeded, theoretical considerations as to the power absorbtion of the milling machine have been left on one side. This compels the author to pass over a considerable quantity of work which he has carried out in this direction. As the result of innumerable practical tests, he has endeavoured to build up a formula by means of which it would be possible to attain certain theoretical results which should coincide with the results obtained in practical work, even if only approximately. It was not only that the tests made and the tables composed therefrom scarcely ever permitted of such a condensation of the tables as would allow of the formulation of certain fixed data, but every time he thought he had found the right track and applied the data obtained to practical work, practice proved that they were entirely fallacious.

It is, of course, true that a certain power absorbtion can be determined theoretically and that the results so obtained will not show a greater divergence than from $\frac{1}{2}$—2 H.P. but since practical experience shows that the difference works out at from 100—150 %, it cannot be said that the expression „fallacious" is at all too strong.

The mechanism of the milling machine absorbes a certain amount of power for its own movements; this absorption of power is dependent on the dimensions and type of the machine, so that it cannot possibly be determined absolutely.

The power absorbed by the milling machine depends on:—

The dimensions of the surface to be milled.

The depth of cut.

The cutter speed.

The ratio of feed and cutter speed.

The kind of material.

The tendency of the material.

The quality of the cutter.

The construction of the cutter.

The condition of the cutterteeth every moment of the milling process.

These are factors which not only differ at every moment, but which in their various combinations give rise to such divergencies, that the laying down of any regular formula is wholly and entirely out of the question.

In his work „Fraiser und deren Rolle bei dem derzeitigen Stande des Maschinenbaues" Professor von Knabbe has gone exhaustively into the theory of this subject as a result of his own experiments and those of Ernest Hartig and Prof. Hart, but, when he proceeds to tabularize, even as a result of partially presumptive data, we see at once that for seven different cases he arrives at the result that the H.P. required to cut away 1 Kg. of material per hour is respectively . 13, . 03, . 11, . 07 and . 03, differences thus of . 03 and . 13, or 400 %, and further, that the material cut away in Kg. per H.P. per hour amounted for these seven cases to 7.7, 28.7, 8.71, 14, 7.64, 13.3 and 35.4, differences again of 7.7 and 35.4 Kg. or about 450 %.

We ourselves do not wish to risk laying down even general data relative to the power absorbtion of milling machines, especially when we consider that the term „milling machine" embraces everything from the small hand milling machine for turning out small brass work in large quantities to the gigantic machine tool illustrated in fig. 314, but notwithstanding the small amount of satisfaction which the following conclusion affords, shall confine ourselves to the maxim: „The power absorbtion of the milling machine is entirely dependent on the factors mentioned above."

The question of power absorbtion is furthermore not of primary importance as regards the use of the milling machine, indeed, we doubt very much whether in general machine construction, a manufacturer has ever seriously considered the question of power absorbtion in connection with the question as to the general type of machine tool he will adopt for his particular needs.

It may generally be accepted that as regards efficiency, the milling machine is not inferior either to the drilling or slotting machine, though, in this respect it certainly is behind the planer and the lathe.

Under these circumstances it is impossible for us to agree with the conclusion drawn by Prof. von Knabbe in the work referred to above when he asserts that the H.P. required to cut away 1 Kg, of material per hour amounts to .32 for the planing machine as against .11 for the milling machine, i. e. approximately $^1/_3$ of that needed for the planer, and are entirely opposed to its adoption as a general rule; it depends entirely on the question as to whether the work done was exceptionally favourable or unfavourable to one or other of the two types of machines, as also to the construction of the tools on which the tests were made. Nothing spoils such a question more than exaggeration and disappointed expectations, and we cannot believe that any industrial concern would find their expectations realised should they decide upon the general adoption of the milling machine simply and solely for the sake of reducing the power absorbed; no, on the contrary, the true economy of the milling machine is to be seen in the *time occupied* in carrying out the work and other advantages connected with the use of the milling machine.

Tests have been made by Mr. DeLeeuw of the Cincinnati Machine Tool Co. on horizontal milling machines similar to those illustrated in fig. 198 for the purpose of determining the power absorbtion required to cut away a given quantity of material on milling machines of diverse construction in order to find out to what extent the construction of the machine effects its power absorbtion, as also to determine the influence exerted on the power absorbtion required for cutting away a certain quantity of material by diverse feeds and speeds and depth of the cut. In principle, it is entirely erroneous to begin exclusively by calculating the power which can be transmitted by the driving belt. It is indeed true that the belt must be capable of transmitting the power which the machine can absorb, but of what use is it if the belt can transmit a high power if the other parts of the machine are not in proportion? Or, of what use is it if the belt can transmit high power, a greater part of which is wasted in the machine itself? The only question for the user is:—"What power can be transmitted to the cutting tool, which is, after all, the only point at which the power absorbed can be turned into useful results"?

In the whole of Mr. DeLeeuw's tests the metal to be cut was of the following specifications:—

Combined carbon	.16%
Silicon	.008%
Manganese	.51%
Phosphorus	.086%
Sulphur	.041%
Tensile strength per square inch	52378lbs.
Limit of elasticity	30313
Elongation per cent of length	50%
Per cent reduction of area	54%

The test blocks used were 18 inches long, 5½ inches wide and 5½ inches thick. The ends were milled to provide means for holding the block on the table of the milling machine. In all tests a spiral cutter with nicked teeth was used, 3½ inches in diameter, 6 inches face and for a 1½ inches arbor. The cutter was made of high speed steel.

The machines were driven by an electric motor, belted to the machine. The power consumed was ascertained by the reading of ammeter and voltmeter, and the amount of metal removed by measuring width and depth of cut and the amount of feed per minute. The feed on all the machines used was obtained by direct gear transmission so that the proportion of the gears could thus be accurately determined.

These tests showed considerable differences in the efficiency of the machines, that is, there was a considerable difference in proportion between the horsepower developed by the motor and the quantity of material cut away. The tests also showed that the efficiency of the milling machines was relatively low as compared to the lathe. This latter might have been expected considering the nature of the cutting tool. As has already been said, the main problem in a machine shop is not to save power, but to get the greatest possible output. If, on account of the cutting tool employed, the milling machine is really behind other tools as regards efficiency, this cannot be regarded as detrimental to this type of machine, since its other advantages far outweigh this deficiency in practical work.

The fact that one machine is so much more efficient than another of the same type is however of considerable importance, seeing that in proportion to the power absorbed, the output of one machine is so much more than that of another of the same size.

It shows that the less efficient milling machines:—

1. Use a needlessly large amount of power.
2. Have less capacity than they might have for removing metal.
3. Use a large amount of power constantly for the purpose of breaking down the machine.

It must thus be the aim of the designer to produce a machine of the highest possible efficiency as a power transmitter so as to ensure the loss of as little power as possible between the source of power, i. e. the driving belt and the cutting tool which turns the power used into practical results.

It goes without saying that everything cannot be sacrificed to the attainment of this object but must be combined with all the other good features which favourably affect the rational application of the machine.

The tests were of three kinds, viz:—

1. To determine the amount of metal removed per H.P. per unit of time (efficiency).
2. Tests determining the efficiency of the feed mechanism.
3. Tests determining the efficiency of the driving mechanism.

A serie of tests was made with a depth of cut of $^1/_{16}$ inch: then with a depth of $^1/_8$ inch, $^3/_{16}$ inch, $^1/_4$ inch and $^3/_8$ inch so as to determine the efficiency by a gradually increasing depth of cut. These tests were repeated four times so as to prevent the possibility of any error being made. The cutter was sharpened each time before starting a complete series of tests, and not resharpened during test.

For each depth of cut a number of different feeds were used for the purpose of finding out what influence the rate of feed exerted on the efficiency. In all cases the even feeds were used starting with the second, (next to the lowest) and increasing thus: 2nd, 4th, 6th, 8th, 10th etc., up to the highest feed. It was of course impossible to go through the entire series with the deeper cuts, as the belt could not transmit the power required but slipped. This slippage of the belt was at all times the end of the test for that depth except where the entire scale of feeds could be used up to the highest feed. The test during which the belt commenced to slip, was not used in plotting curves.

The tests showed that the ammeter readings gradually increased from the first to the fourth series. This was probably due to the gradual dulling of the cutter.

In plotting the curves, the test readings were first corrected:—the power readings given by the volt and ammeter by means of the efficiency chart of the motor; the amount of metal for loss of speed of the machine (⁰/₀ of belt slippage). The curve as plotted is the curve of the average value of the powers. Where the curve shows an amount of metal removed of, say $5\frac{1}{2}$ cub. in. per minute, this amount may be due to a depth of cut of $^{1}/_{16}$ inch and a feed of 16 inches or to a depth of cut of $^{1}/_{8}''$ and a feed of $8''$, or perhaps a depth of cut of $^{1}/_{8}$ inch and a feed of 8 inches.

The amount of power required to remove a given amount of metal varied with the speed, depth of cut and feed per minute and seems to have a tendency to the minimum when the section of the chip removed per tooth approaches most nearly a perfect square. The diagrams given in figs. 456—457 show curves giving the relation existing between power required and metal removed under different conditions of speed, feed and depth of cut. They are partially derived from the tests described and partly from tests made for the special purpose of ascertaining these relations. The fact that the power required changes with these conditions of feed, speed and depth of cut made it impossible to plot a single curve giving relation between power and metal removed. Besides, the same speeds and feeds obtainable on one machine were not obtainable on another, even the percentage of belt slip varied with the different machines. For these reasons averages have been plotted.

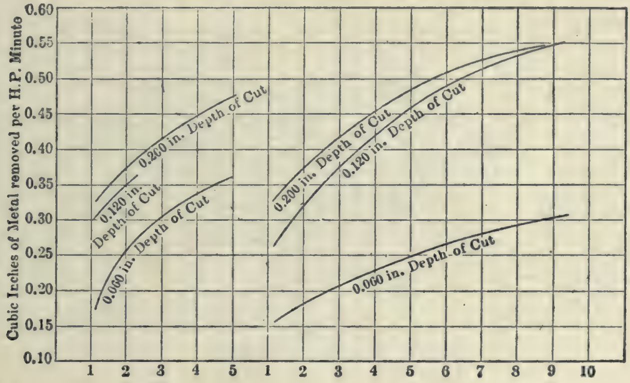


Fig. 456. Fig. 457.

Cutting speed 12 ft. per minute. Cutting speed 32 ft. per minute.

Work of 1 H.P. min. measured in cubic inches of metal removed, feed increasing.

Power required for feed mechanism.

Various tests have shown that a considerable amount of power is required for the feed drive of the milling machine, amounting even to 40 % of the total power applied. The feed mechanism of a N^{0}. 4 Cincinnati milling machine can amount to as much as 3½ H.P. If, in that case, the feed is 20 inches per min. (the highest feed found on a modern milling machine), then the pressure against the cutter must be:—

$$\frac{3\frac{1}{2} \times 33000 \times 12}{20} = 69.300 \text{ lbs.}$$

provided there are no losses in transmission. Further, it is not likely that the greatest amount of horse power is required

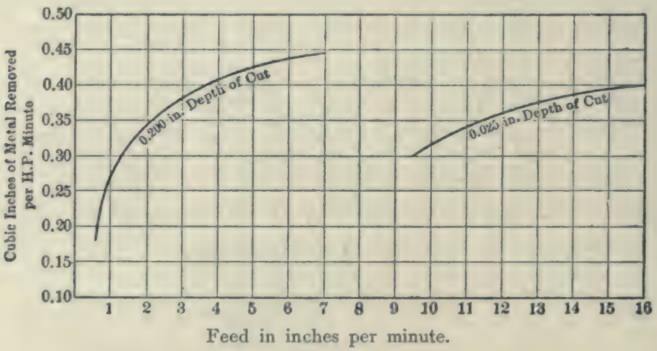


Fig. 458.

Cutting speed 45 ft. per minute, feed increasing.
Work of 1 H.P. minute measured in cub. inches of metal removed.

for the feed at its maximum number of inches per minute. It is more probable that the maximum of feed power is used for 10 inches feed or less per minute, in which case the pressure would be in the neighbourhood of 140.000 lbs.

A machine using 6 H.P. at the cutter would thus require a total of 11½ H.P. supposing that 2 H.P. is lost in the driving mechanism with the 3½ H.P. lost in the feed mechanism.

Assuming the cutting speed to be 40 ft., the pressure at the circumference of the cutter must be:—

$$\frac{6 \times 33.000}{40} = 4950 \text{ lbs.}$$

and this must also be the approximate pressure against the table screw instead of 140.000 lbs. Of course all these figures are assumed but they illustrate the computations which led up to the second series of tests relative to the amount of power required for the feed mechanism.

In order to determine the efficience of the feed mechanism, the total amount of power used was measured as well as the amount of work done by the table. As the amount of power required varied considerably, the idea of using an individual motor for the feed alone was abandoned since it would be impossible to obtain an efficiency chart covering the whole range of powers used by the motor. The necessity thus arose of giving the motor a fairly constant load by artificial means. For this purpose the square box shown in fig. 462 was mounted on the spindle arbor; it had a paddle inside and a number of obstructions which made the required resistance for the water in the box. By increasing the amount of water in the box and by giving the paddle various speeds, any load could be produced and this load was constant. The box was kept from rotating by resting against the overarm of the machine. The artificial load of the motor was adjusted until it came within the efficiency curve of the motor. The part of the apparatus used for measuring the work done by the table consisted of a dynamometer, graduated up to 8000 lbs.

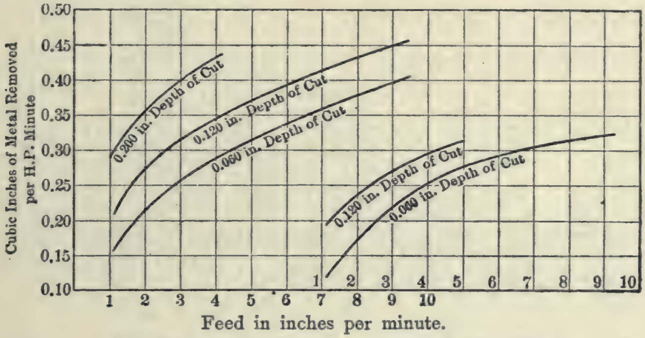


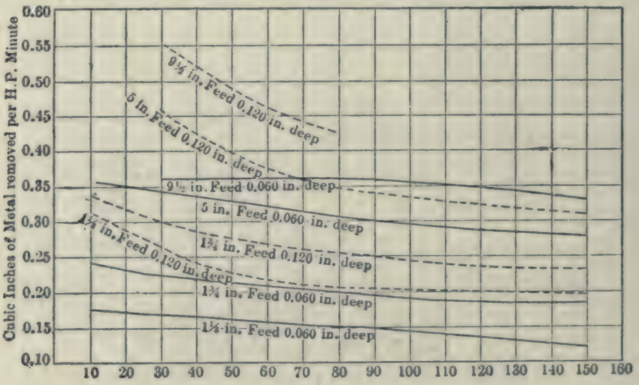
Fig. 459. Cutting speed 67 ft. per minute.

Fig. 460. Cutting speed 150 ft. per min.

Work of 1 H.P. min. measured in cub. inches of metal removed, feed increasing.

One end of this dynamometer was attached to the table of the milling machine whilst a chain at the other end of the instrument was wrapped around a drum which was mounted on a brake of the Weston type. The brake itself was used only as a safety device, being set at sufficient pressure for the test but slipping before there was any danger of wrecking the machine.

It had been originally intended to set the brake for a certain pressure and to have the table feed under this pressure for some length of time but it was found that the brake was too jerky in its action. The mode of working was therefore changed and the test was carried out as follows:—All even feeds were taken, beginning with the second lowest and going up to the highest. For each feed the following pressures were selected:—1000, 2000, 3000, 4500 and 6000 lbs. The entire series was repeated once if nothing happened to spoil the test. If something happened to disturb the proceedings and to cause doubts as to the correctness of the results obtained, the entire result of the test was dropped and no curve was plotted until two complete series of tests had been made without interruption.



Cutting speed in Feet per minute.

Fig. 461.

Cutting speed 15 ft per minute speed increasing.
Work of 1 H.P. Minute measured in Cubic Inches of Metal removed.

A sensitive ammeter reading $\frac{1}{10}$ amperes was used. With a given feed, an entire series of pressures was gone through, after which the amount of feed was changed for the new series, etc. Before taking a series of readings, the feed mechanism was disconnected to get the reading of the dead load. Another reading of the dead load was taken after each series of readings was completed. During the tests special attention was paid to the rotary speeds of the machines and the readings of the dynamometer and ammeter.

Fig. 463 shows the curve of average values plotted from the readings, from which it appears that the efficiency of the feed mechanism is not 20%, which goes to show how necessary it is that efforts should be made to bring about an improvement by improving the construction of the mechanism. The great importance of a higher efficiency in the feed gearing cannot be over-estimated. It may seem that 20% efficiency is still so low that it makes little difference whether this figure is somewhat higher or lower. It may seem at a first glance that it is of little importance to the user whether 80% or 90% of the feed power is lost in

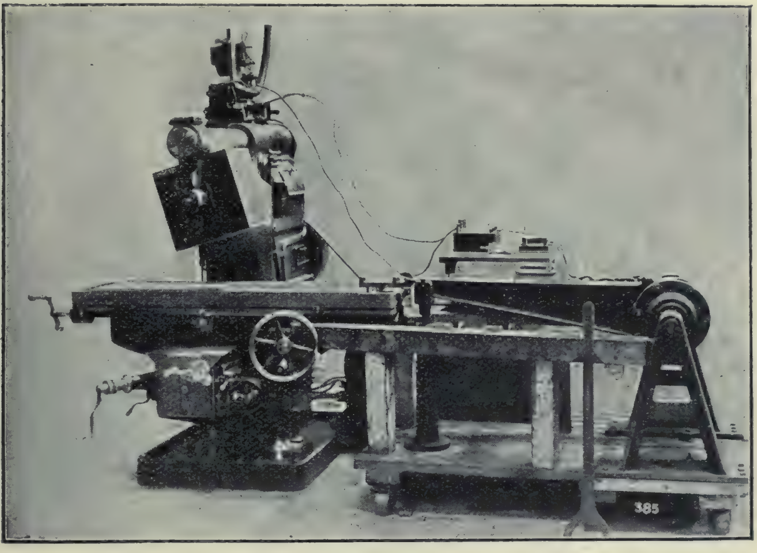


Fig. 462.

transmission. But a more careful look at this problem shows the importance of high efficiency very clearly. If 3 H.P. out of 10 are used for feed on a machine of which the feed efficiency is 10%, then 0.3 H.P. is actually used for this feed. If 10 H.P. is used for the entire machine, that is, for feed and drive, then 7 H.P. is left for the spindle drive alone and therefore the amount used for the feed is $^3/_7$ of the amount used for the spindle drive.

With a machine having a feed efficiency of 20%, or twice as much, the amount of power used for the feed will be $^3/_{14}$ of the amount of power used for the spindle drive alone or $^3/_{17}$ of the total amount used for the machine. If again this amount is 10 H.P. then the amount used for the feed will be 1.76 H.P. as against 3 H.P. in the first machine, and the amount left for the spindle drive will be 8.24 as against 7 H.P. in the first machine, giving an increased spindle power of 18% available for cutting. Of the 3 H.P. used by the first machine for the feed, only 2.7 H.P. are employed to wear down the feed mechanism, whilst of the 1.76 H.P. used for feed in the second machine, 20% or 0.352 H.P. is usefully employed, whereas the remainder or 1.41 H.P. is used destructively. It will be seen, therefore, that the power used to break down the

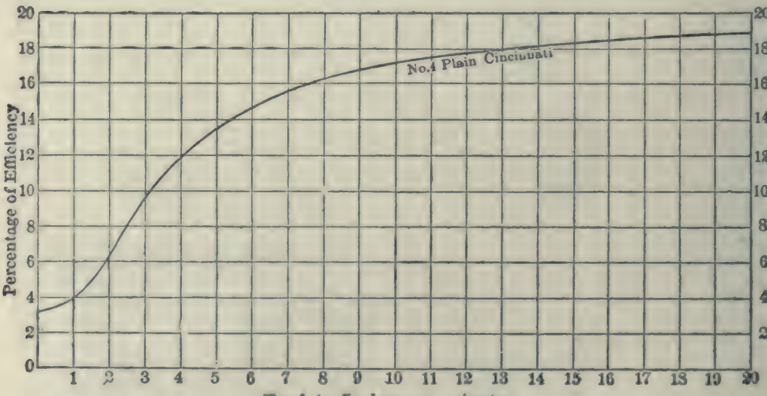


Fig. 468.
Feed efficiency curve.

machine is almost twice as great in the first machine as it is in the second.

Efficiency of Driving Mechanism.

The third series of tests were taken to determine the efficiency of the machine drive. These tests were carried as per fig. 464 on a combination of two N⁰. 4 Cincinnati milling machines connected by a stout shaft. The feed works were removed, as were also knee, saddle and table, so that nothing remained but the bare frames and driving works. One of the machines was driven by a motor while the other drove a generator. The current thus generated was dissipated in a water rheostat, by means of which the amount of current could be closely regulated. There was a set of electric instruments both for motor and generator, so that all readings could be taken simultaneously. Both machines were driven by belts, the amount of slip being carefully checked. If the generator volt meter showed considerable drop and the tachometer showed about the proper speed at the first driving shaft of the first machine (motor machine), then the belt on

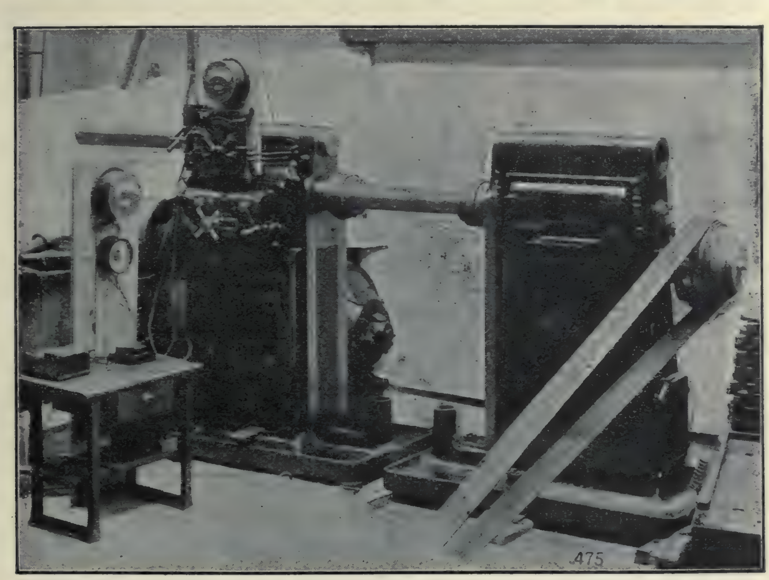


Fig. 464. Apparatus for testing the efficiency of a milling machine.

the generator must have slipped. If, however, the tachometer showed a drop, then the belt from the motor to the first machine must have slipped. During the tests the same transmission was used on both machines.

Various tests were taken at different loads, viz:—125, 100, 80 and 70 amperes. Each set of tests was carried out over a number of speeds, namely, the lowest, third, fifth, etc. up to the highest but one. After the necessary corrections for slip, efficiency of motor dynamo, etc., the efficiency of the two machines was plotted as per diagram fig. 465, which shows that same varied from 67 to 79.7%.

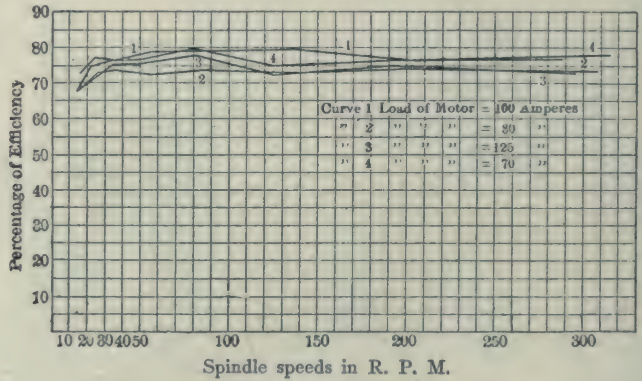


Fig. 465.
Efficiency curves of a No. 4 Cincinnati high speed miller.

It cannot be gainsaid that workpieces which are suitable for the milling machine can be tooled much quicker and with a far better finish on this machine than on either the planer, slotting machine or lathe. The output of the milling machine to that of the same work on the lathe, the slotting machine or planer depends entirely on the nature of the work.

The milling machine has taken over a greater part of the work of the planing machine, is doing more and more of the work previously done on the lathe whilst practically the whole of the work done on the slotting machine can be done much quicker and better on the milling machine. The milling machine, however, is not adopted for cutting keyways in bores but since there are now special machines on the market for this class of work, the slotting machine can really be regarded as an abandoned type of machine, the necessity for which no longer exists.

Although the milling machine can supersede the planer in a large number of cases, still it often happens that the planer can do the work equally as well and perhaps better, so that in comparing milling and planing work it is especially a question as to which type of machine is better adapted for each special kind of work. Only a comparatively small amount of lathe work can be carried out on the milling machine, at any rate when output and quality have to be considered.

To attain the best results from the milling machine it is a matter of the greatest importance that the workpiece should be mounted properly on the machine and the most profitable manner of working be chosen.

In the following chapter an attempt will be made to give further particulars in connection therewith by means of examples derived from practical work.

CHAPTER XIII.

Milling Operations.

Workpieces widely divergent in form can be machined on the milling machine.

The following examples will serve to give an idea not only of the manner in which various workpieces are clamped to the milling machine but also of the manner of working and the kind of cutters employed in different cases.

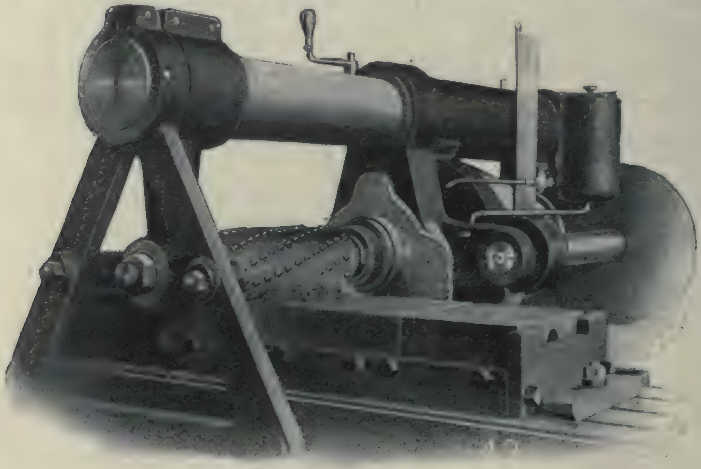


Fig. 466. Surface milling.

Fig. 466 shows the milling of rectangular pieces of cast iron. As it is here more a question of cutting away a large quantity of material than of obtaining a true surface, a cutter with inserted teeth is used. The workpieces, four in number, are clamped in a jig, a plate at the front taking up the end pressure. The removal of $^{1}/_{8}$ inch of metal from these workpieces, $8^{1}/_{4}$ inches wide over a length of 32 inches occupied 4 minutes.

Fig. 467 shows the milling of the surfaces of castings. The width of the workpieces is $8^{1}/_{2}$ inches and with a feed of 16 inches per minute a cut of $^{3}/_{32}$ inch is taken. To prevent too great an axial pressure on the spindle, a pressure which in the case of such heavy milling work would be likely to prove detrimental, a right and a left-handed spiral cutter are combined, which effectually prevents undue end pressure. Two workpieces pinched in a special vise, are milled simultaneously.

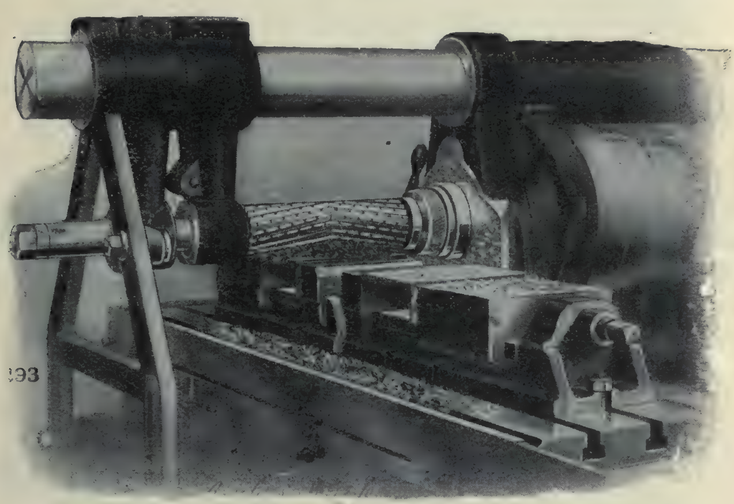


Fig. 467. Surface milling.

In this case as well as in that illustrated in fig. 466, the arbor is supported on either side of the cutter.

The workpiece in fig. 468 is of such form that it can be bolted to a base plate, which in its turn is clamped to the table. The workpiece which is flat at the top but has a groove running through the centre, is milled on all sides simultaneously except, of course, on the underside. To accomplish this, a combination gang of cutters is mounted

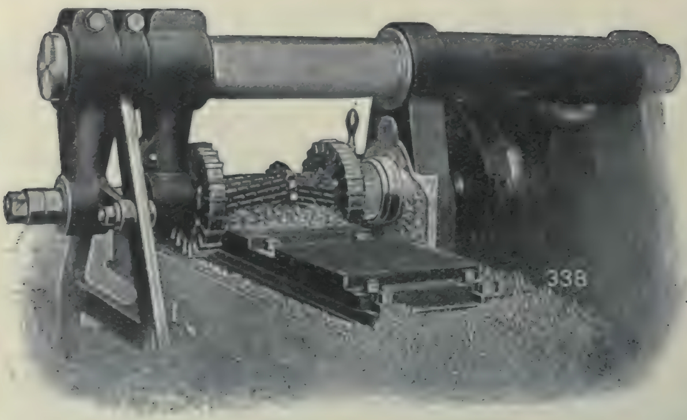


Fig. 468. Milling composite surfaces.

on the arbor. Two shell cutters with right and left-hand spiral teeth are mounted on the arbor for machining the upper surface with a slotting cutter between them, the whole being enclosed by a pair of face cutters with inserted teeth for milling the sides. These castings are $10^1/_4$ inches wide.

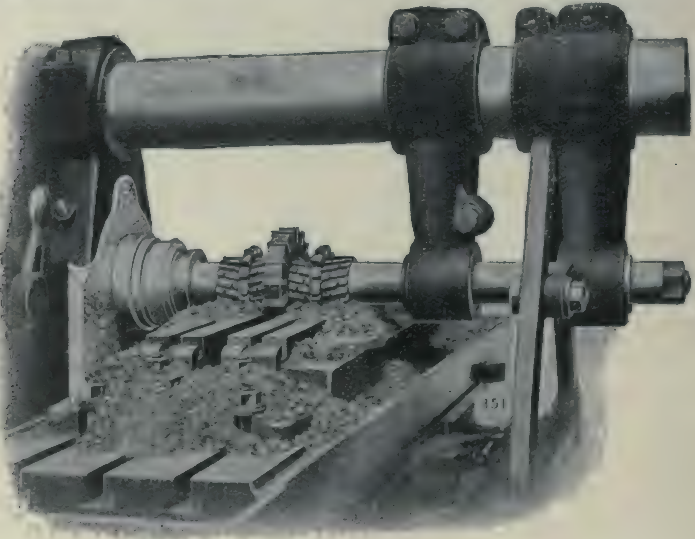


Fig. 469. Simultaneous milling of two workpieces.

In fig. 469 a combination of cutters is shown milling two workpieces at the same time, which are clamped in a special vise. $^3/_{16}$ inch stock is removed all over, a semicircular slot being milled in the centre and the sides finished at the same setting. The face cutter mills the two sides of the workpieces, an equal gang of cutters being placed at the right and left-hand sides. The left-hand side of the face cutter thus belongs to the left-hand gang of cutters and the right-hand side to the right-hand gang.

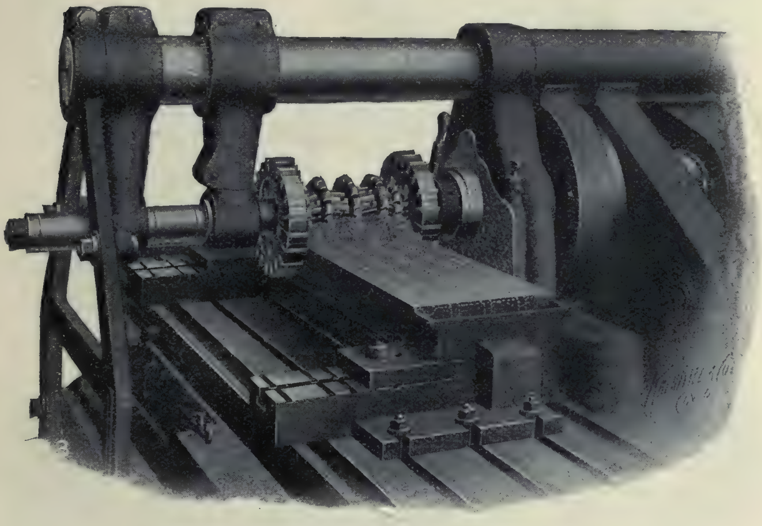


Fig. 470. Milling the top of a milling table.

The two workpieces were milled in 18 minutes, that is 9 minutes each, including time required for clamping. The actual cutting time was 4 minutes, a planer with two heads working at 18 meters cutting speed per minute, took 36 minutes to finish one,—just 4 times the milling time.

Fig. 470 shows the complete milling at one cut of the top of a milling table. The combination cutter consists of no fewer than 13 separate cutters. The two outside cutters each have a diameter of $7^1/_2$ inches and mill the sides. The 6 small shell cutters, which mill the surface of the table, have a diameter of $3^{1}/_{2}$ inches. The two cutters for the oil grooves and the 3 for the T slots have a diameter of $5^{1}/_{2}$ inches. The dotted lines on the workpiece show the metal to be removed. The table which is 9 inches wide and $35^{1}/_{2}$ inches long, is milled in 25 minutes including chucking. In this case also the cutters are carried closely between the bearings. The table is clamped by a special clamping device. As the underside of the table has already been machined, this clamping device allows of the grooves being milled in the table in precisely the correct place, not only as regards the upper surface but, at the same time, with regard to its bearings.

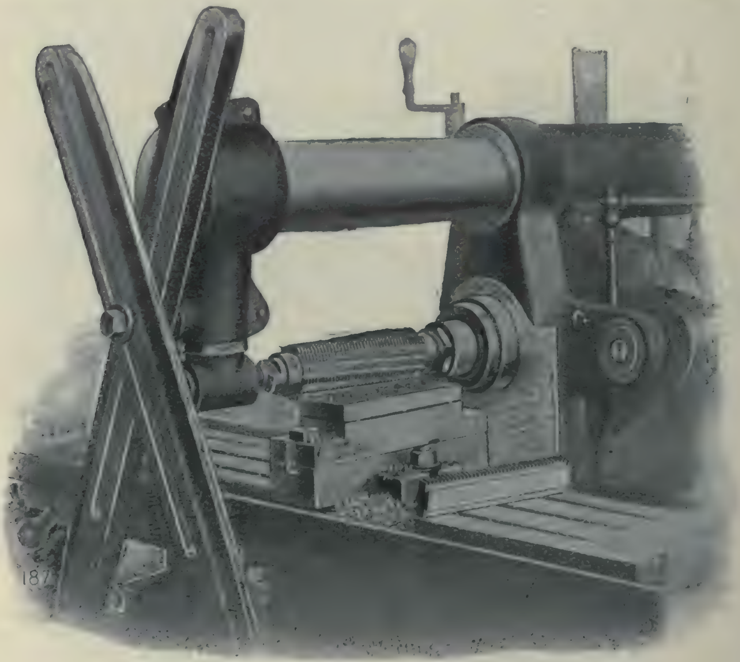


Fig. 471. Rack milling.

Racks are usually cut tooth by tooth by a gear cutter. In fig. 471, however, all the rack teeth of a drill sleeve are cut simultaneously. The cutter consequently consists of just as many teeth as the rack. The racks are 16 pitch, the length of the rack being 8 inches. The teeth are milled at one cut, the rack being completed in one minute.

Fig. 472 shows three face cutters milling three grooves simultaneously in a number of workpieces. The workpieces are chucked in a jig in which these pieces, otherwise so difficult to chuck accurately, fit perfectly whilst the projections are also clamped by plates.

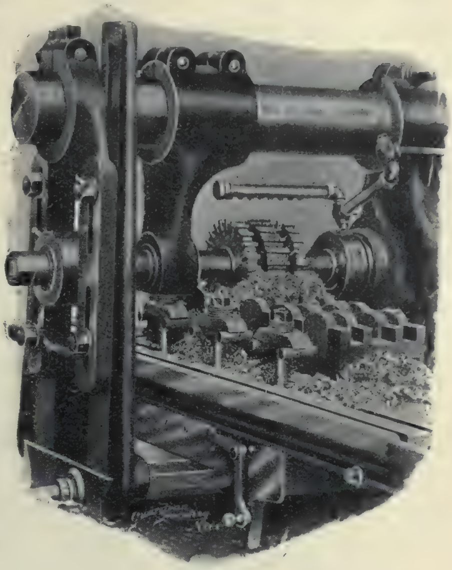


Fig. 472.
Simultaneous milling of more than one workpiece.

In fig. 473 the entire frame of a 8 H.P. gas engine is to be seen on the milling machine and with a combined cutter consisting of five different cutters, the whole of the fitting surfaces for the covers are milled simultaneously.

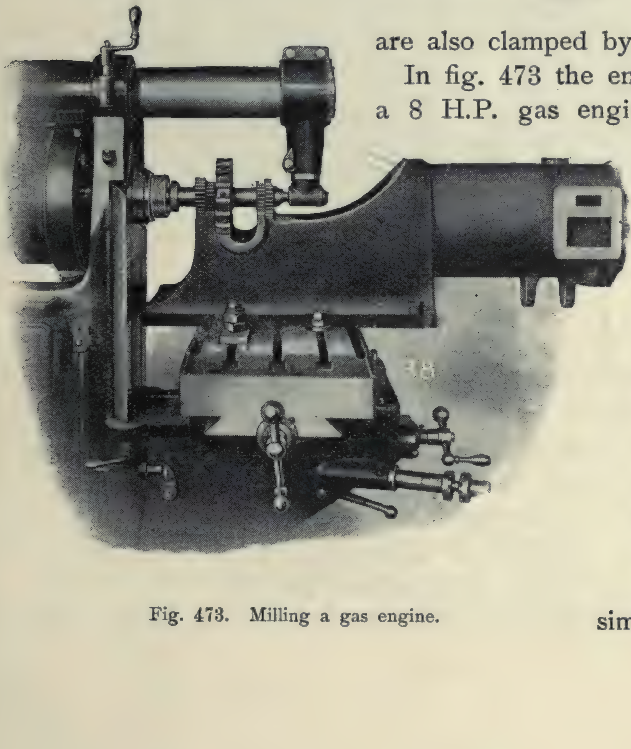


Fig. 473. Milling a gas engine.

In all the examples given so far, the cutters have been mounted on an arbor and were consequently provided with a bore and with but one exception, cut on the contour, thus acting principally as shell cutters.

In all the examples the table had automatic longitudinal motion and with the exception of the workpiece shown in fig. 473, where the form of the workpiece rendered this impossible, the spindle was carried close up to the cutters by bushings on the overhanging arm and the bracings which, in their turn, rested on the knee, thus ensuring a rigid connection between the arm and the knee.

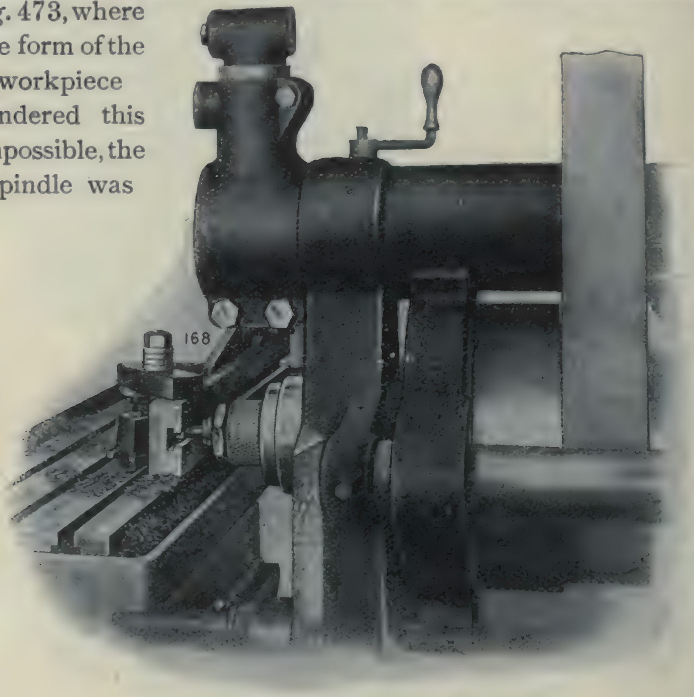


Fig. 474. Undercutting T-slots.

In fig. 474 on the other hand, the cutter which is provided with a taper shank is placed in the conical bore of the spindle, into which it is pressed by a nut.

The workpiece has to be provided with a T slot. For this purpose a groove is first milled over the entire length by a slotting cutter, the width of the groove being equivalent to the narrowest part of the ⊤slot; after this groove has been milled the workpiece is turned 90^0 and clamped in the position shown in the illustration. The workpiece is not held by any special clamping device but by means of bolts. To accomplish this, one end of the clamping plates rests on the workpiece, the other end on a support of equal height. If that part of the workpiece on which the clamping plates rest has been machined, it is advisable to put a piece of cardboard between the clamping plates and the workpiece. In cases such as that shown in fig. 474, it is also desirable to put a piece of paper between the table and the workpiece; this serves two purposes, firstly, to increase the friction between the two superincumbent parts, thus holding the workpiece more firmly, and secondly, to prevent any damage to table and workpiece.

In the case of workpieces such as those under consideration, careful attention should be given to a detail which is of importance in connection with good workmanship and accurate work, viz:—the supporting piece at the other end of the clamping plates. Owing to lack of proper appliances, the most terrible bungling frequently results. A really good support is a piece of hard wood of the same height as the workpiece plus the thickness of the cardboard placed between the clamping plates and workpiece. The exact height is a matter of importance and can better be a trifle too high than too low, the exact height of the workpiece plus the thickness of the cardboard is, however, the most desirable. If the support is higher, the sharp edge of the clamping plate will press on the workpiece leaving a mark; as soon, however, as the clamping plate lies somewhat slanting or only bears on the edge of the surface, it is liable to damage the edge of the workpiece which has often been previously finished. It is still worse if the support is too low, as the clamping plate will then only bear on the outside edge of the workpiece which it will not only injure but since pressure is only exerted on one side, the underside is not clamped fast on the table, the clamping is not firm and therefore, not true.

If the workman were given the opportunity of obtaining supporting blocks of the exact height required, he would, in the majority of cases, feel sufficiently interested in his work to take care to do so, but most times the workman has neither the time nor the opportunity for this. In such a case he gets together all the supporting blocks on hand and tries to make the best of a bad job by sometimes using two or three blocks of different height, which are either too high, or too low, with the inevitable result that the workpiece is damaged and the work, when done is inaccurate.

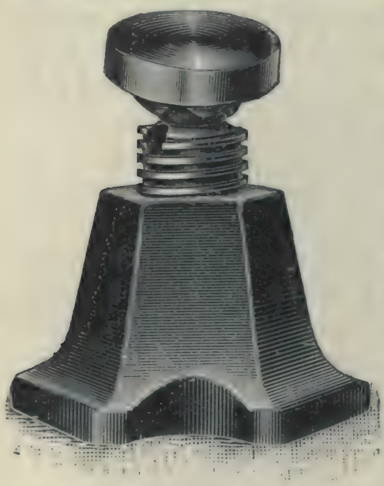


Fig. 475. Supporting block.

On looking at fig. 474, it will be observed that no wooden blocks are used but a proper supporting block as shown in fig. 475. Within certain limits, this supporting block can be adjusted to the exact height required, whilst the head swivels in any direction on a ball bearing so that it forms a suitable support even for slanting workpieces.

The cutter used in fig. 474 works principally on the contour, the front is also provided with teeth but these are only to secure an accurate surface of the T slot and consequently remove very little metal.

The cutting tool in fig. 476, in this case a face cutter, is mounted directly on the spindle. A vertically adjustable supporting block is also used here as a support for the clamping plate. The form of the workpiece lends itself better for resting on the flat of the side and not vertically. The surface to be milled is, however, longer than wide; in the position in which it is now placed the diameter of the face cutter exceeds the width of the surface to be milled, the long side being in the length. By this means the whole of the surface is milled at one operation by the longitudinal motion of the table. In suchlike milling work it is necessary that there is sufficient depth of cut for the cutter, as otherwise the teeth will traverse the hard surface of the casting and very soon become dull. It is also worthy of note that the cutter is placed as near to the main bearing as possible to prevent vibration.

Fig. 477 illustrates the milling of spiral teeth in a tool steel blank which has a diameter of 4 inches and is to be provided with 24 teeth at an angle of 14 degrees.

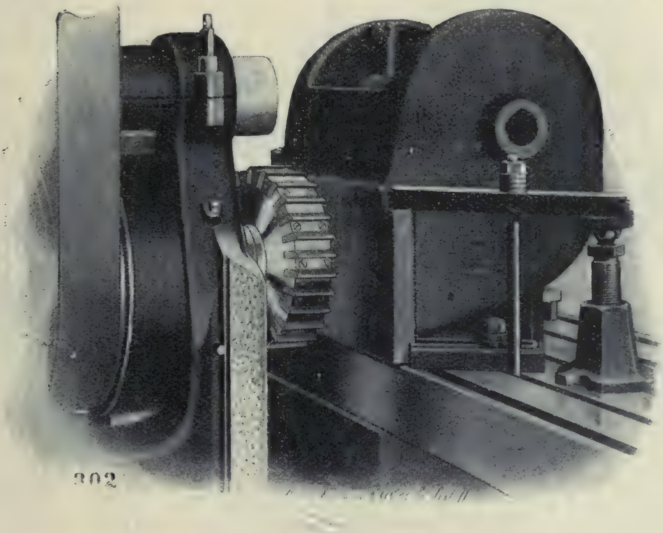


Fig. 476. Milling with face cutter.

The dividing head has a single-threaded worm and a wormwheel with 40 teeth.

On referring to the table on page 115, it will be seen that for 24 divisions, dividing circle 39 can be taken and on this a full turn and 26 holes must be moved over.

The required division can be calculated without recourse to the tables, as follows:—

$$n = \frac{g \cdot v}{t} = \frac{40}{24} = 1\frac{2}{3} = 1\,\frac{26}{39}.$$

The angle at which the table must be set, viz:— 14^0, is known.

Upon reference to table XVI on pages 148 and 149, it will be found that if the teeth of a cutter of 4 inches diameter are at an angle of 14 degrees the spiral lead will be 50 inches; granted that the feed screw of the table is as usual $^1/_4$ inch pitch, the ratio of the change gears will thus be:—

$$\frac{50}{10} = \frac{5 \times 10}{2 \times 5} = \frac{30 \times 50}{15 \times 20}$$

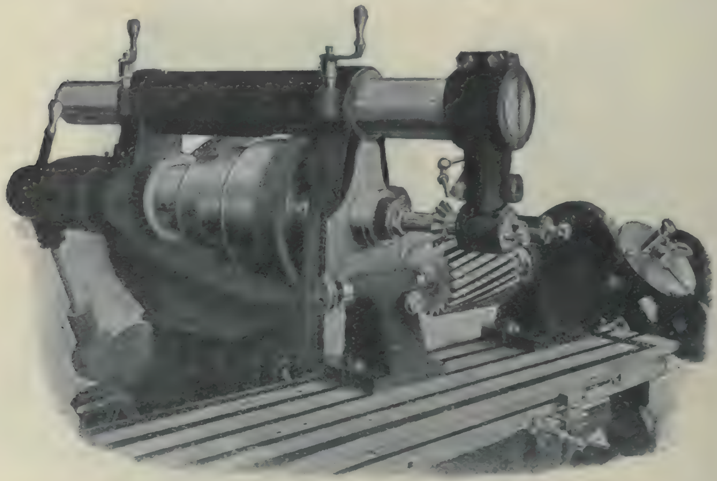


Fig. 477. Milling spiral teeth.

since as the wormwheel has 40 teeth and is single-threaded, the constant c (see page 146) $= 10$.

Should it be desired to calculate the change gears instead of taking them from the tables, then according to figs. 193—195, the angle A and a are known since $\angle A = 90^0$, $\angle B = 90^0 - 14^0 = 76^0$ and $a =$ circumference of the cutter-blank; b the spiral lead which it is necessary to know in order to calculate the ratio between the spiral lead and the pitch of the lead screw of the table from which the change gears are calculated, is according to page 141 equal to $a \,.\, tg\, A$.

$$\left.\begin{array}{r} a = 4 \times 3.14 = 12.56 \\ tg\, A = tg.\, 76^0 = 4.011 \end{array}\right| \begin{array}{l} a\, tg.\, A = 12.56 \times 4.011 = 50.37817 \\ \qquad \text{or} \infty \text{ 50 inches.} \end{array}$$

The table is thus set at an angle of 14 degrees. Next, the index plate on which the division 39 appears, is mounted. The segment is so adjusted that the two legs cover 27 holes. Then the change gears are mounted in such a manner that 15 and 20 are the driving gears and 30 and 50 those driven, since only when the table has travelled 50 inches may the cutterblank have completed one full turn; when the cutter has been mounted on the arbor, the cutterblank is placed in such a manner that the line *c a* of the blank passes through the centre *o*, (see fig. 107). The table is then set to the requisite height. According to table III, page 64, the depth of the tooth of a cutter of 4 inches diameter is $^1/_2$ inch. The grooves are first cut to a depth of $^3/_8$ inch, after which the work is gone over with a depth of cut of $^1/_8$ inch.

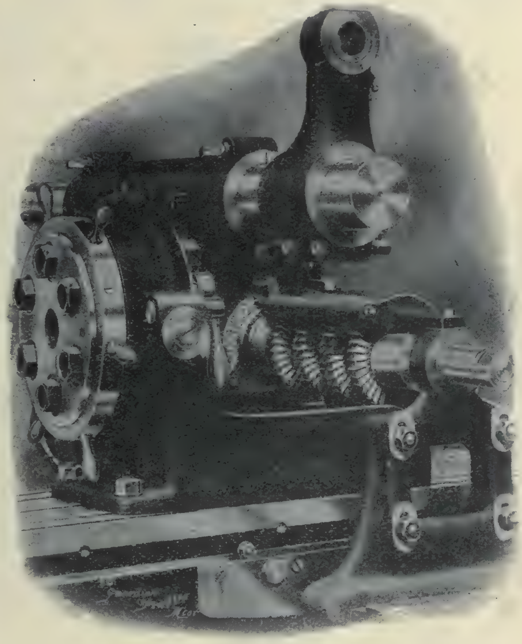


Fig. 478. Milling hexagons.

Figs. 478 and 479 illustrate an attachment on the milling machine for milling the hexagon heads of bolts and nuts. Six bolts are placed in the vertical plane of a vertical revolving head. Four side cutters are mounted on the arbor at an equal distance from one another. As the feed is vertical, the braces between the knee and overhanging arm cannot be used, but short bracings are attached to the knee to carry the arbor. The attachment is placed under the cutters in such a manner that their contours traverse the bolt heads whilst the table is fed vertically.

When the cutters have traversed the bolt heads, the table is lowered, the revolving head in which the bolts are chucked is turned $^1/_6$th of a revolution and the traverse of the cutters is repeated. After having been traversed six times, the six bolt heads are finished, so that it can be reckoned that for each traverse 1 bolt head is completely milled on all six sides. As a matter of fact, for the first three traverses eight sides are milled simultaneously, four sides being milled during the last three traverses.

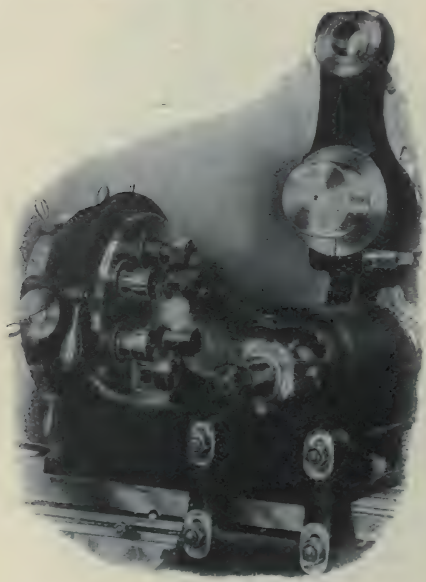


Fig. 479. Milling hexagons.

In figs. 480 and 481 two attachments are mounted on the milling machine as described on pages 352 and 357, figs. 408 and 417, by means of which the cutter rotates parallel to the spindle.

Fig. 480 shows the cutting of pawlteeth, the length of blank exceeding the transverse movement of the table; not only would it be impossible to carry out this work without resetting, but if the rack were reset and reversed, then other cutters would have to be employed which would mean a considerable loss of time and interruption to the work. In order to prevent this, the workpiece is placed lengthwise on the table and the attachment mounted on the milling machine causes the spindle of the attachment to rotate square on the main spindle.

The attachment shown in fig. 481 serves the same purpose as that illustrated in fig. 480 but is more universal. The spindle of the attachment in fig. 480 can only rotate square on the main spindle, whilst that in fig. 481 can rotate at any angle. The principal object of this is to permit the milling of wide-angle spirals, which would necessitate placing the table at too wide an angle if the cutter were mounted on the spindle. With this attachment, however, the table can retain its position square on the spindle whilst the cutter can be set to the desired angle for the spiral line to be cut.

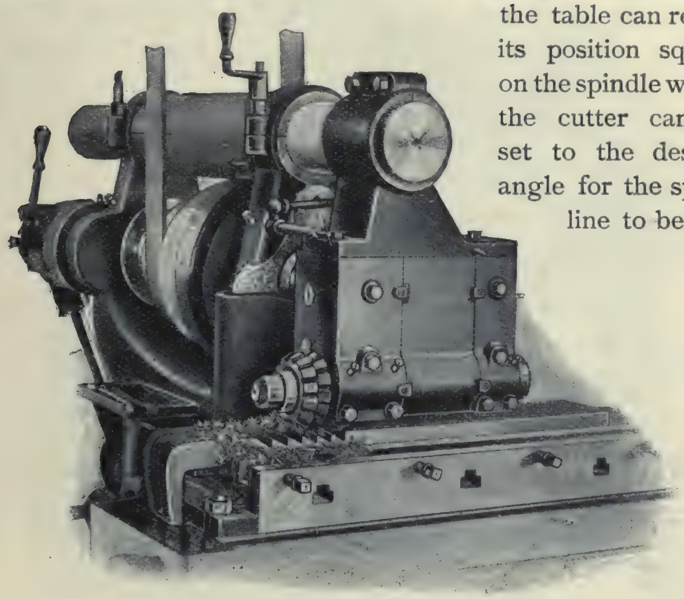


Fig. 480. Milling the teeth of a pawl.

For cutting spirals, the feed screw motion of the table is usually transmitted to the dividing head spindle by the change gears. For a pitch as in fig. 481, however, the table motion will be very small in comparison to the rotary motion of the dividing head spindle.

The spindle of the attachment is set at such an angle that the centre line is square on the spiral line.

Fig. 482 illustrates a vertical milling attachment on a horizontal milling machine as described on pages 348 and

349, figs. 404 and 405. A face cutter of 8 inches diameter mills thin plates perfectly true. It is desirable for two reasons to mill workpieces such as those shown on the machine in fig. 482 with a face cutter instead of an shell mill. In the first place, the chucking of similar thin plates is not easy. No clamping plates can be placed on the top face as this must be machined all over. The workpiece must consequently be clamped at the sides but then there is very little to keep the workpiece accurately on the table surface, the more so as the sides of the plate cannot be clamped firmly in order to prevent their twisting.

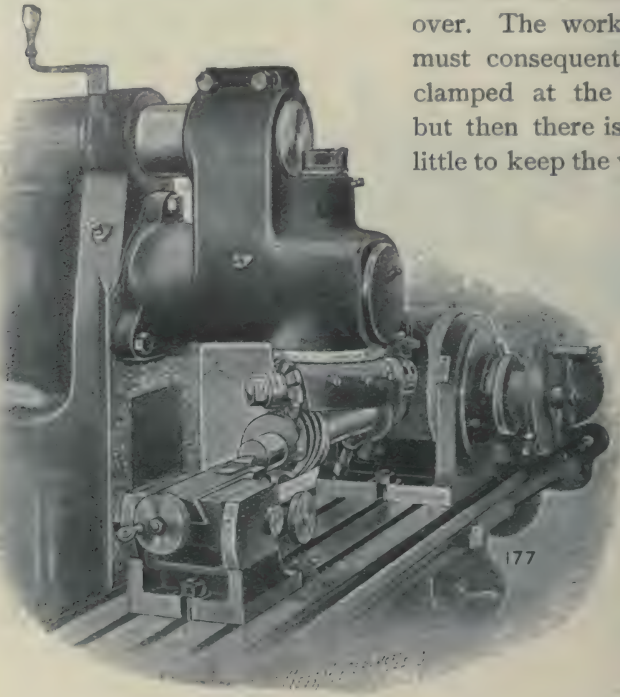


Fig. 481. Cutting 3 pitch steel gears.

With shell mill cutting, the teeth try to lift the workpiece, whereas the face cutter on the contrary exercises but a slight pressure on the workpiece in a longitudinal direction which is counteracted by clamping plates taking the end thrust, whereas the cutter presses the workpiece to the table surface.

Furthermore, it is scarcely possible to mill a thin plate with a width such as that in fig. 482 perfectly true with a shell mill; with a face cutter on the other hand, the teeth cut the metal away on the working side whilst the teeth on the other side pass over the work again and thus finish the surface.

Fig. 483 shows the manner of working with the attachment illustrated and described on page 356, fig. 415, which converts the milling machine into a slotting machine since the motion of the tool is up and down. Square holes are being slotted in the workpiece shown in fig. 483. Holes are drilled in the four corners in which the slotter begins to work. The tool can be turned to an angle of 90° whilst owing to the longitudinal and transverse movement of the table, accurate square holes can be slotted. Steel

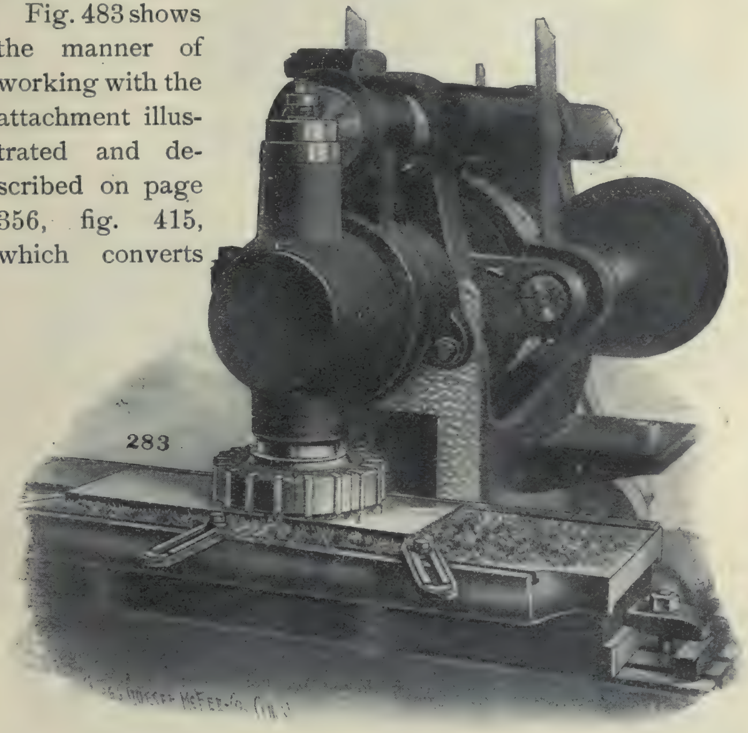


Fig. 482. Surface milling with face cutter.

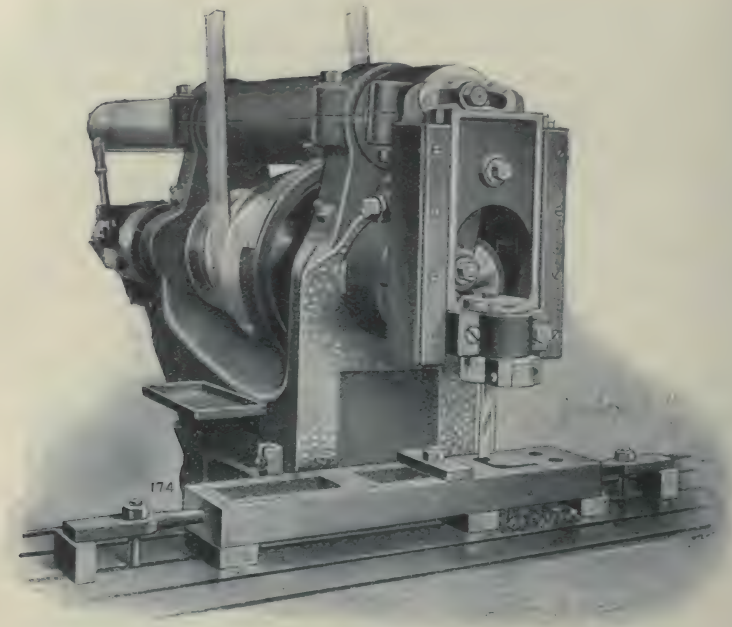


Fig. 483. Slotting on the milling machine.

dies of irregular shape are principally slotted in this manner. A few interesting examples of milling work on the vertical milling machine are given in fig. 484 and those following, from which it will be seen for

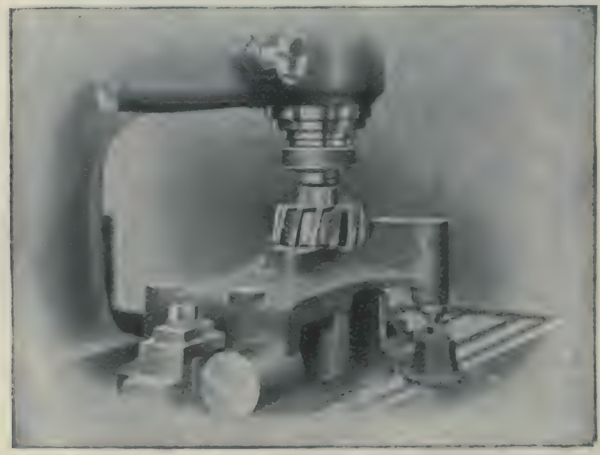


Fig. 484. Surface milling on a vertical milling machine.

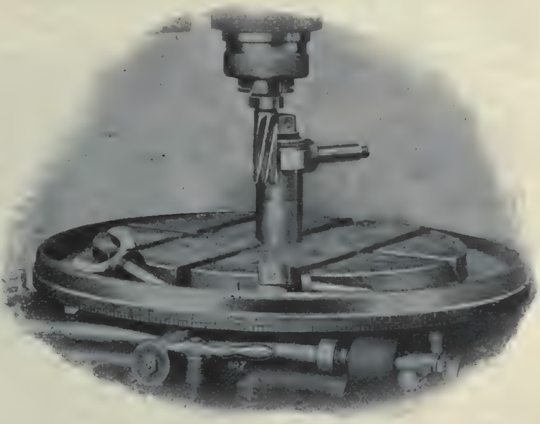


Fig. 485.
Circular milling on the vertical milling machine.

what a great variety of work the vertical miller is adapted. The machine part in fig. 484 has four surfaces to be tooled, all of which must be parallel and equidistant from one another. These surfaces are to be milled with an end mill.

When one of the surfaces is finished the vertical adjustment of the workpiece is read from the graduated collar on the spindle and the exact distance can then be determined without the employment of any other measuring. The projecting part of the workpiece which is liable to spring during the operation of milling, is prevented from so doing by the supporting block shown in fig. 475.

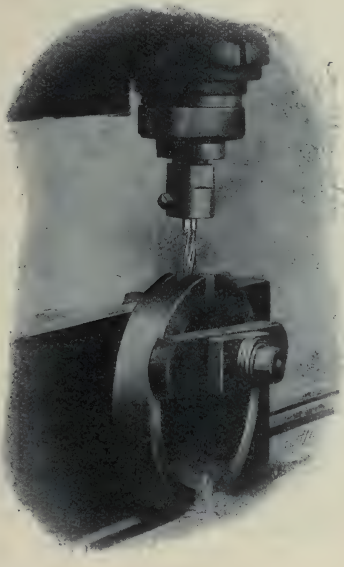


Fig. 486. Milling a T-slot.

Fig. 485 illustrates circular milling for which the vertical milling machine is eminently adapted. In general machine construction a very large number of workpieces are met with having both in and external circular parts followed by a tangent line so that such parts cannot be machined on the lathe. Consider for example the various parts in connection with the building of steam engines, such as slide valve rods, connecting rods, eccentric half rings, levers, cranks etc.

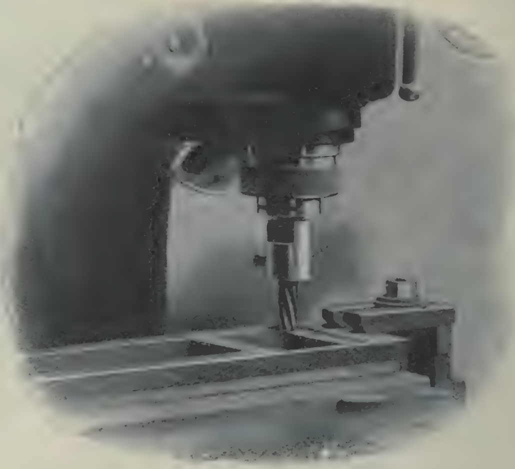


Fig. 487. Milling with an end mill.

The circular table placed on the main table of the milling machine, has a bore in the centre, recessed on the underside; a bolt with round head fitting the hole is placed in the table, the projecting part being turned to a diameter that just fits the bore of the workpiece.

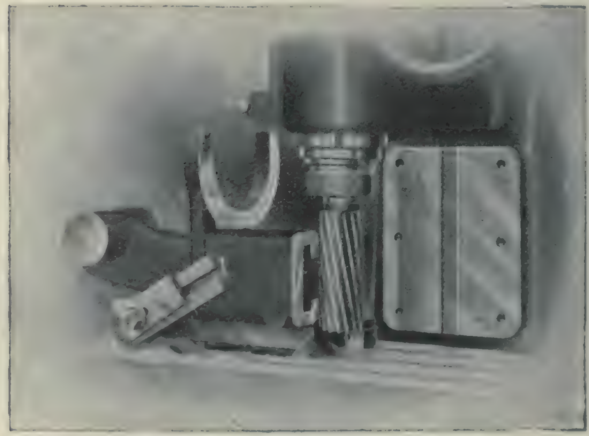


Fig. 488.
The end mill on the vertical milling machine.

After the workpiece has been fastened with a nut, an automatic rotary motion is imparted to the table and the workpiece is milled to the required diameter. The rotary movement is tripped at the point where the circular form changes into a straight line. When the workpieces have holes larger than the bore in the table, cones are employed (see figs. 454—455) which permit of the workpiece being mounted centrally.

Fig. 486 shows the milling of a slot in a cast iron ring. Without the vertical milling machine, suchlike work would have to be drilled, after which it would have to be slotted or filed by hand. With the end mill, the vertical milling machine does the work better and quicker.

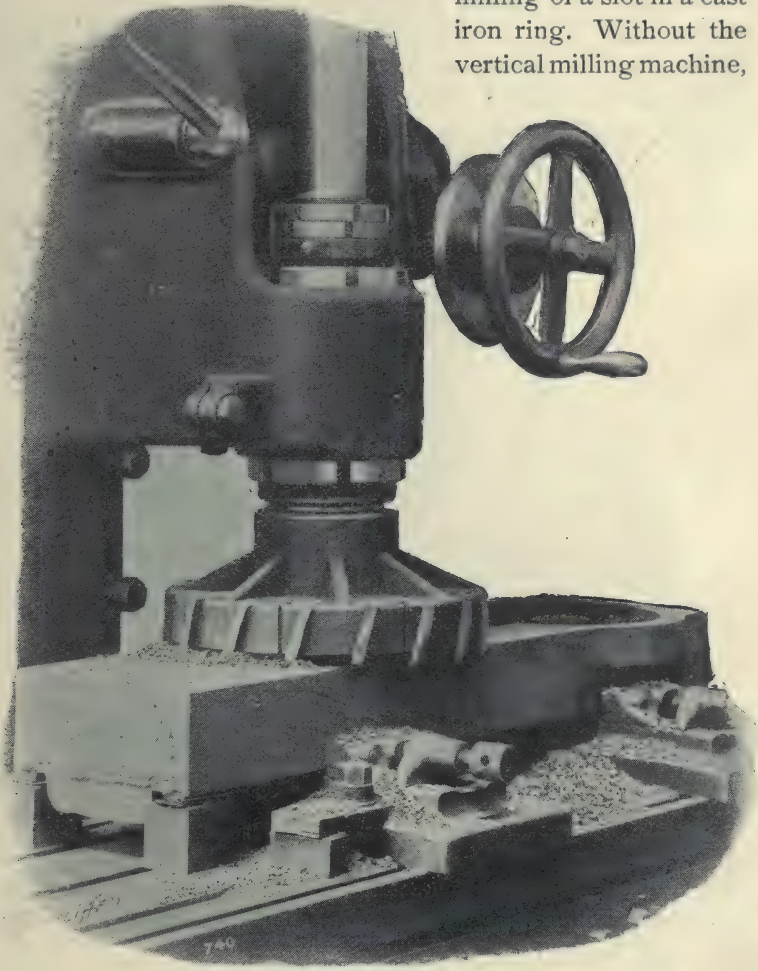


Fig. 489. The face mill on the vertical milling machine.

Fig. 487 is an example of the use of the end mill for milling recesses in a casting. A great variety of similar workpieces can be machined in this way, which could otherwise not be done accurately.

Fig. 488 is a good example of what a diversity of surfaces can be milled on a workpiece by means of the end mill and face cutter without resetting the workpiece. The same cutter has machined the two surfaces of the hubs of this workpiece, the two sides of the fork, has milled the vertical surface at the same time and could, if necessary, also mill various horizontal surfaces.

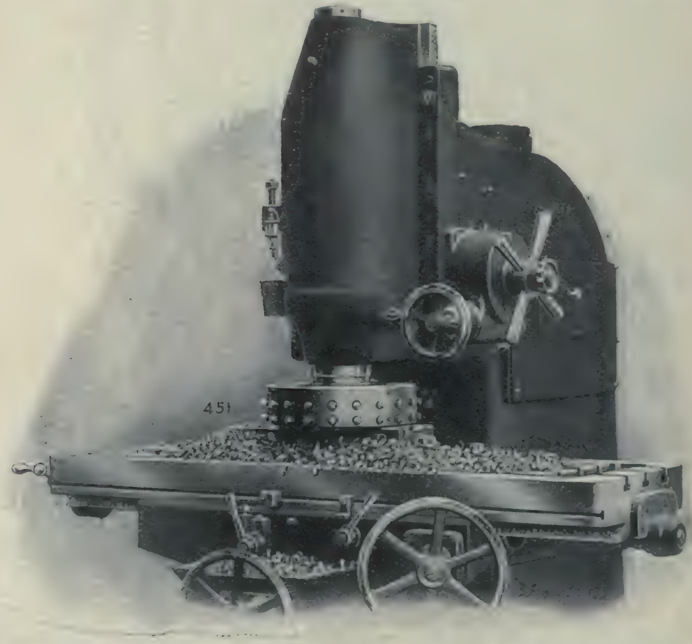


Fig. 490. Face milling on a Cincinnati vertical high duty milling machine.

Fig. 489 gives an example of heavy surface milling work on the vertical milling machine. The workpiece, the underside of which is of irregular form, rests on flat pieces and is securely chucked by four vises which in turn are clamped to the table with ordinary clamping plates. The mill is a face cutter of 12 inches diameter. The cutting speed 75 ft. per minute, the depth of cut $^5/_{32}$ inch, the width of the workpiece 11 inches, and the feed $7^1/_2$ inch per minute.

Fig. 490 is an example of heavy cutting with the vertical high duty milling machine illustrated on page 316. The workpiece is 20 point carbon steel. A 12 inches cutter is taking cuts while running at 17 revolutions per minute, which gives a surface speed of 44 inches per minute, 10 H.P. being absorbed in the cut which is 6 inches wide and $^1/_4$ inch deep, the feed being 6 . 7 inches per minute. This means that 10 cub. inches of steel are removed per minute, or 1 cub. inch per nett H.P. minute.

CHAPTER XIV.

The Backing off Lathe.

If, after the mechanical treatment on the lathe, the cutter-blank is provided with teeth on the milling machine, and has become a cutting tool, the backed off cutter cannot be finished on the milling machine, but the back of the tooth, must be machined on the backing off lathe.

The backed off cutter is at the present time so extensively used on the milling machine, (at least 95 percent of the formed cutters are backed off), that the backing off lathe can be regarded as being inseparably connected with the milling machine.

Tools for the manufacture of backed off cutters may be divided into two classes:—

1. The backing off lathe.
2. Backing off attachments.

The backing off of the teeth of cutters may also be accomplished in two ways:—

1. A rotary motion is imparted to the cutterblank whilst the cutting tool at the same time moves at intervals in a straight line towards the centre of the blank, the result being that a logarithmatical spiral is formed.

2. The workpiece has not only a rotary movement on its centre line but at the same time, revolves eccentrically, so that although not a true logarithmatical spiral, still one which is near enough to accuracy is obtained.

The backing off lathe works in accordance with the first principle; the backing off attachment usually according to the second.

The backing off lathe is a machine tool differing only in some special points from the ordinary lathe and can consequently be used without alteration as an ordinary lathe and in factories where it cannot be fully occupied with the backing off of cutters, it is indeed often used as such, whilst the backing off attachment which is mounted on the ordinary lathe, is so constructed that during the rotation of the workpiece it moves towards the cutting tool.

As long as the width of the cutter is not too large, the cutting tool is given the negative form of the cutter and is fed in square on the centre of the cutter. To what extent this can be done, depends considerably on the bore of the cutter, that is to say, the diameter of the arbor on which the cutter is mounted since the arbor must be of sufficient strength to withstand the pressure of the cutting tool on the workpiece.

Formed cutters composed of two widely different profiles are manufactured in sections. If, however, the width of the cutter is too great, the feed of the cutting tool square on the centre of the cutter is no longer possible, the tool must traverse the width of the cutter in a longitudinal direction and be fed in a little more each time after the cut has been completed, as in the case of ordinary lathe work.

If the body of the cutter is either cylindrical or taper, this can be accomplished without any special attachment; if, however, the cutter has a profile form, it will be absolutely necessary to conduct the tool by a guide.

Still another case is possible, viz:—when the backed off tooth also forms a spiral line, in which case the backing off movement of the rest must be increased or decreased according as the spiral is right or left handed and in such a ratio that after the carriage has traversed the length of one spiral lead, the increase or decrease shall also amount to one complete revolution. This increase or decrease of the backing off motion is obtained by an arrangement on the lathe by means of a set of differential gear wheels driven by the lead screw, which effects the increase or diminution in fixed proportion to the travel of the carriage.

When the cutter to be backed off is a hob, the increase or diminution must be very high.

For the manufacture of formed backed off cutters with spiral teeth a fully equipped backing off lathe will be required, the backing off attachment being more used for the simpler cases.

As the backing off consists in a jerking motion, both the lathe spindle and the rest must be exceptionally rigid.

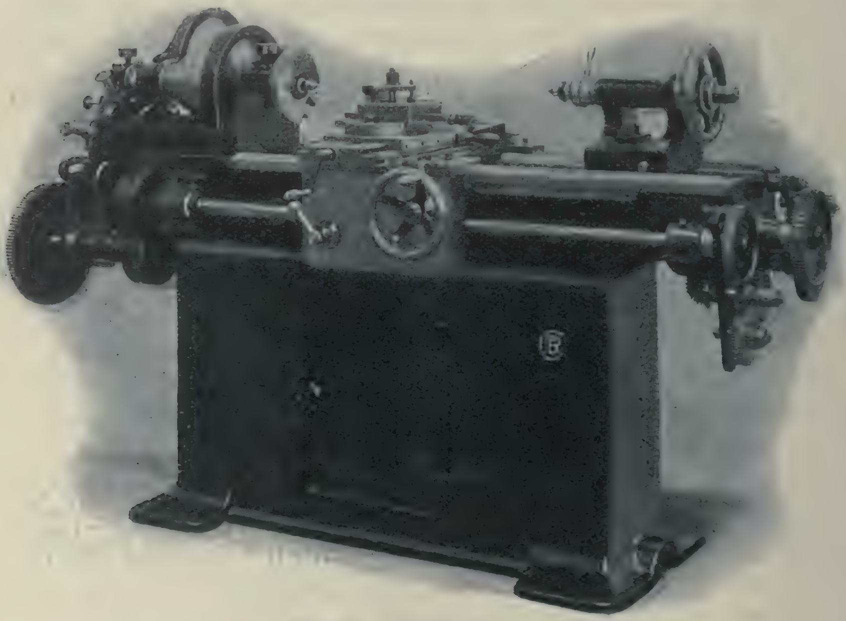


Fig. 491. Backing off lathe.

Bearings of ample dimensions for the main spindle, broad bearing surfaces for the carriage and rest are absolutely indispensible for the attainment of a good cutter, though much also depends on the skill of the workman.

The arbor on which the workpiece is mounted must be kept as strong as possible and be of tool steel; the arbor must fit the cutter precisely, being keywayed, the cutter being thrust against an edge of the arbor by a nut.

Just where the dog is mounted on the arbor there must be a flat for the bolt in order that the dog may not move over the arbor but will maintain an invariable position with regard to the lathe spindle. This is obtained by the use of a dog with a bent tail which will mesh in a notch of the catch plate.

Fig. 491 illustrates a backing off lathe. There is a high ratio of back gearing viz:—1 : 16. The backing off motion of the rest is obtained by means of a separate shaft housed in the centre of the bed. The carriage is moved longitudinally by means of the lead screw.

Cutters up to a diameter of 10 inches can be backed off on this machine, threads with pitches from $^1/_{230}$ to 10 inches can be cut and backed off, cutters from 2 to 40 teeth with straight, right or left hand spiral teeth with a lead of from 4 to 400 inches can be machined. Such a coarse pitch, which can only be required for the backing off of hobs for cutting worm wheels, is obtained by transmitting the motion of the lead screw not from the lathe spindle but from the cone pulley direct. With double back gear, the lead screw will then rotate sixteen times as fast as when driven from the lathe spindle since the cone pulley runs sixteen times faster than the lathe spindle.

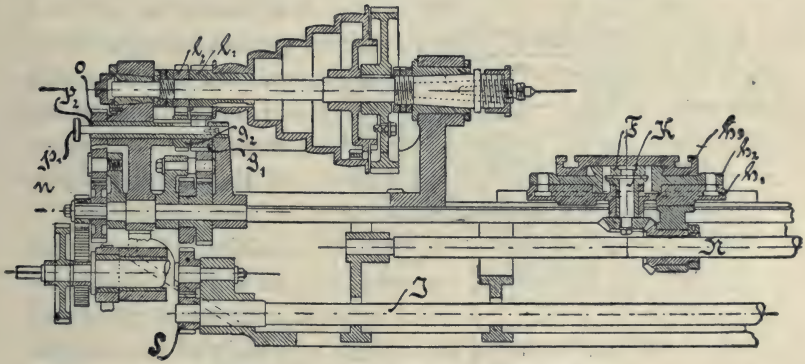


Fig. 492. Sectional view of backing off lathe.

Fig. 492 gives a sectional view of the backing off lathe shown in fig. 491. To the cone pulley which runs on the main spindle, is attached the pinion l_1 for the back gearing next to pinion l_1 the pinion l_2 both of which drive the gear wheels g_1 and g_2 placed underneath, which run on the hollow shaft p_2. By means of the key p_1, both g_1 and g_2 can be connected with the hollow shaft p_2 which can consequently be made to rotate quickly by means of l_1 or slowly by means of l_2. At the other extremity of the hollow shaft p_1 and keyed to it, is the gear wheel o which transmits motion to the lead screw. When cutting a very coarse pitch, the shaft p_2 is driven by the gear wheel l_1 which is connected to the cone pulley. When running with back gearing in for one revolution of the lathe spindle, the shaft p_2 which drives the lead screw, makes sixteen revolutions, so that a quick longitudinal motion of the carriage in proportion to the lathe spindle speed is thus rendered possible.

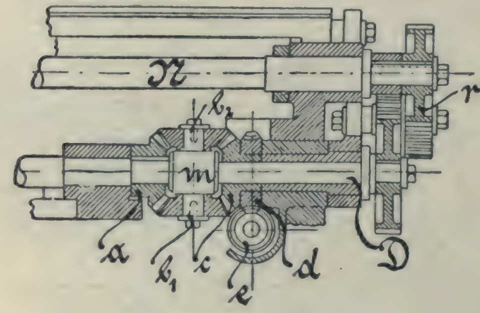


Fig. 493. Differential gears.

The pinion s on the shaft J is driven by the gear wheel g_1 through a train of intermediate gears; the differential gears for the increase or diminution of the backing off motion are mounted on this shaft J and consist of the mitre gears a, b_1, b_2 and c, the worm wheel d and the worm e, all of which are mounted on the right hand end of J (fig. 493).

The shaft D, the continuation of J, is driven by the differential gears. At the left hand extremity is the cross head m on the taps of which and running idle are the two mitre gears b_1 and b_2 which mesh in a and c. Except when backing off spiral shaped teeth, the mitre gear c does not revolve. The gearing from J to D takes place as follows:—The mitre gear a meshes b_1 and b_2. When rotating, these two mitre gears revolve not only on their own axis, but since both mesh the mitre gear c connected to the wormwheel d which meshes the worm e, they must both revolve over the mitre gear *c*, carrying the crosshead *m* and consequently the shaft D with which it is connected, with them. The speed ratio between the shaft D and J is 2 : 1.

When the worm *e* causes the wormwheel *d* as also the mitre gear *c* to rotate in the same direction as that in which the mitre gear *a* rotates, the result is that the mitre gears b_1 and b_2 run faster, since they are not only *driven* by the mitre gear *a*, but at the same time, they *run over* it. As a consequence, the speed at which the shaft D rotates is increased in the same ratio as the increase of speed of the gears b_1 and b_2.

If the wormwheel *d* which is driven by the worm *e*, rotates in the opposite direction to the mitre gear *a*, then the speed at which the shaft J revolves is reduced in the same ratio as the reduction of the gears b_1 and b_2.

According as right or left-hand spiral teeth have to be backed off, it is by this means rendered possible that the backing off movement shall take place either earlier or later.

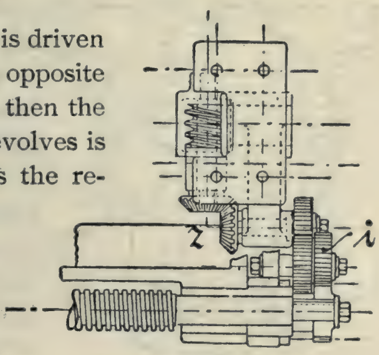


Fig. 494.

How much earlier or later this backing off movement must take place depends entirely on the lead of the spiral and can, consequently, be very divergent. In order to regulate this at will, the wormwheel *e* is driven by a set of mitre gears *z* from the lead screw through change gears, (fig. 494), the ratio of which is calculated in the usual way.

If one intermediate gear is mounted, so that the lead screw motion is transmitted in the same direction, the backing off movement will follow a left-hand spiral; by mounting a second intermediate gear, the direction of movement is reversed and a right-hand spiral obtained. These change gears are placed at the right-hand side of the bed on the tailstock side (see fig. 491).

Shaft D causes shaft N to revolve by means of change gears *r*, (fig. 493), which shaft governs the number of to and fro movements of the tool. The ratio between these gears thus depends on the number of cutter teeth.

The shaft N drives the backing off movement, that is, the to and fro motion of the rest and the lathe tool. A mitre gear is mounted on this shaft with which it rotates, whilst a mitre gear with which it meshes, causes the vertical stud K to rotate. To this stud K is attached the cam F (fig. 495), which moves the rest to and fro. The stud K is the axis on which the compound rest can swivel so that the to and fro movement is obtained in every position of the rest and thus flat, slanting and sideway backing off is possible. On either side of the feed screw of the rest are the springs *f* which force the roller L which is attached to the rest, against the cam. As this springs more or less, the speed at which the tool is returned can be regulated in accordance with the width of the previously milled groove.

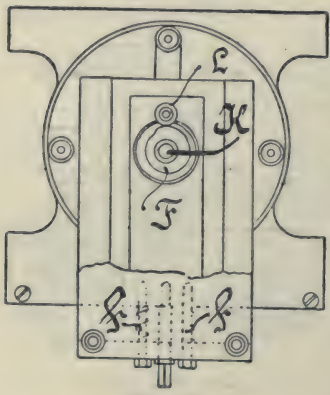


Fig. 495.

The cam can also be changed so that the to and fro movement of the tool can be altered at will and can vary according to the kind of cutter from $^1/_9$—$^3/_8$ inch.

When the cam suited to the cutter to be backed off has been duly mounted, the change gears *r* must be calculated and mounted for the number of to and fro motions of the tool.

The gearing from the main spindle to shaft D is such that by a ratio of the change gears per revolution of the main spindle and thus also of the cutter to be backed off 10 to and fro movements are obtained, whilst the ratio of the change gears must be calculated in the same proportion as the number 10 to the number of teeth of the cutter.

If the cutter has 12 teeth, the ratio will be 10 : 12, so that the gears 50 : 60 will suit: if the cutter has 8 teeth, the 10 : 8, i. e. 50 : 40, so that in any case the gear with 50 teeth will be mounted on the shaft N and will thus be the gear driven.

Given that the constant $10 = a$, and the number of teeth of the cutter to be backed off b, the following formula will be obtained:—

$$\frac{a}{b} = \frac{\text{gear driven}}{\text{driving gear}} = \frac{10}{b}.$$

Example 1. Number of teeth to be backed off 21.

$$\frac{10}{b} = \frac{10}{21} = \frac{4 \times 2.5}{6 \times 3.5} = \frac{20 \times 25}{30 \times 35}.$$

„ 2. Number of teeth to be backed off 15.

$$\frac{10}{b} = \frac{10}{15} = \frac{20}{30}.$$

„ 3. Number of teeth to be backed off 27.

$$\frac{10}{b} = \frac{10}{27} = \frac{4 \times 2.5}{6 \times 4.5} = \frac{20 \times 25}{30 \times 45}.$$

„ 4. Number of teeth to be backed off 9.

$$\frac{10}{b} = \frac{10}{9} = \frac{50}{45}.$$

In the case of a cutter with straight teeth the lathe is then ready for work.

If, however, spiral teeth have to be backed off the change gears i in fig. 494 take up the backing off motion earlier or later.

Whether the spiral is right or left handed makes no difference to the ratio of these gears, as for left hand spirals only one gear more must be mounted: the number of teeth on the cutter is also of no consequence as the ratio of these change gears affects the lead of the spiral.

Supposing now that a cutter has to be backed off, the spiral of which has a lead of a 12 inches and that the lead screw has a pitch of $^1/_4$ inch, then, for the longitudinal movement of the carriage over the bed for one lead of the spiral, the lead screw must make $4 \times 12 = 48$ revolutions.

The shaft D must now have its speed increased accordingly and if it should make the same number of revolutions as the main spindle, it should be advanced one complete revolution over a length of 12 inches. As, however, it rotates ten times as fast as the main spindle, it must be increased 10 revolutions whilst the carriage travels 12 inches.

This increased speed is imparted to the shaft D by means of the mitre wheel *c* and the wormwheel *d*, (fig. 493). The worm *e* which drives the wormwheel *d* must consequently make 10 revolutions as many times as the wormwheel has teeth. In the case of the lathe, illustrated in fig. 491, this wormwheel *d* has 32 teeth, so that the worm must thus make $10 \times 32 = 320$ revolutions for 12 inches travel of the carriage.

This number 320 is consequently fixed, so that it is simply a question as to the lead of the spiral when these 320 revolutions of the worm *e* have been completed and this depends on the pitch of the lead secrew and of the spiral lead of the cutter tooth.

Given the number of revolutions of the worm *e*, the constant n, the pitch of the lead screw $g = {}^1/_4$ inch, the lead of the spiral $= e$ in inches, the following formula is then obtained, viz:—

$$\frac{n}{g \cdot e} = \frac{320}{4\,e} = \frac{80}{e}.$$

In the case of a 12 inches lead, the ratio of the change gears will thus be:—

$$\frac{80}{12} = \frac{8 \times 10}{3 \times 4} = \frac{40 \times 50}{15 \times 20}.$$

Example 1. Lead of spiral 21 inches.

$$\frac{80}{e} = \frac{80}{21} = \frac{8 \times 10}{3 \times 7} = \frac{40 \times 50}{15 \times 35}.$$

„ 2. Lead of spiral 33 inches.

$$\frac{80}{e} = \frac{80}{33} = \frac{8 \times 10}{6 \times 5{,}5} = \frac{40 \times 100}{30 \times 55}.$$

„ 3. Lead of spiral 40 inches.

$$\frac{80}{e} = \frac{80}{40}.$$

„ 4. Lead of spiral 56 inches.

$$\frac{80}{e} = \frac{80}{56} = \frac{8 \times 10}{7 \times 8} = \frac{40 \times 50}{35 \times 40}.$$

The two following tables of the number of teeth and leads of spiral are most frequently met with.

Table XXVI.

Table for change gears *r* (fig. 493) for the number of teeth.

$$\frac{\text{N}^0.\text{ of teeth} = t}{10} = \frac{a \times c}{b \times d}.$$

t	*a*	*b*	*c*	*d*	*t*	*a*	*b*	*c*	*d*
2	20	60	30	50	14	70	25	20	40
3	20	40	30	50	16	40	—	—	25
4	20	—	—	50	18	60	25	30	40
5	25	—	—	50	20	60	—	—	30
6	30	—	—	50	24	60	—	—	25
7	70	50	20	40	28	40	50	70	20
8	40	—	—	50	32	60	30	40	25
9	40	60	30	50	36	60	20	30	25
10	40	20	30	60	40	60	25	50	30
12	30	—	—	25	50	60	30	50	20

The foregoing table is drawn up on the presumption that the lathe runs with back gear in as is most frequently the case. In the case of cutters with but few teeth, direct drive can be used, the gearing being accomplished by means of the gears l_1, and l_2. (fig. 492), so that the formula is changed into $\frac{8 \, . \, t}{5} = \frac{a \times c}{b \times d}$.

Table XXVII.

Table (lathe running without back gear).

t	*a*	*b*	*c*	*d*	*t*	*a*	*b*	*c*	*d*
2	60	30	40	25	5	50	25	80	20
3	40	20	60	25	6	60	25	80	20
4	40	25	80	20	7	70	25	80	20

Table XXVIII.

Tables for change gears *i*, (fig. 494) for leads of spiral

$$\frac{l = \text{lead of spiral in inches}}{80} = \frac{a \times c}{b \times d}.$$

l	*a*	*b*	*c*	*d*	*l*	*a*	*b*	*c*	*d*
6	96	24	80	24	80	80	40	32	64
6.66	96	24	72	24	90	64	—	—	72
7	96	28	80	24	96	40	—	—	48
8	96	32	80	24	100	40	—	—	50
9	80	24	64	24	112	40	—	—	56
10	96	24	64	32	120	48	—	—	72
12	80	24	64	32	128	40	—	—	64
14	80	28	64	32	140	32	—	—	56
16	80	32	56	28	144	40	—	—	72
18	64	48	80	24	150	32	80	40	48
20	96	—	—	24	160	32	—	—	64
24	80	—	—	24	180	32	—	—	72
28	80	—	—	28	192	30	—	—	72
30	64	—	—	24	200	32	—	—	80
32	80	—	—	32	224	32	64	40	56
36	80	24	48	72	240	24	—	—	72
40	80	—	—	40	255	30	—	—	96
48	80	—	—	48	280	40	56	32	30
50	64	—	—	40	288	32	64	40	72
56	80	—	—	56	300	48	60	24	72
60	64	—	—	48	320	24	—	—	96
64	80	—	—	64	360	40	72	32	80
70	64	—	—	56	384	40	72	30	80
72	80	—	—	72	400	28	56	32	80

The attachment shown in fig. 496 may render good service in repairing shops. This attachment can be mounted on any lathe bed and since the fact that the lathe is not perfectly accurrate does not affect the working of this attachment in the slightest, it can be mounted on a lathe which can no longer be used for other work.

With this attachment, cutters up to 8 inches in diameter can be backed off both internally, externally and sideways. With this attachment, the rest and the tool remain stationary whilst the cutter makes a rotary movement not only on its own axis but also eccentrically the cutter being turned one tooth farther at the exact point of the eccentric motion. The cutter consequently then makes three movements at the same time.

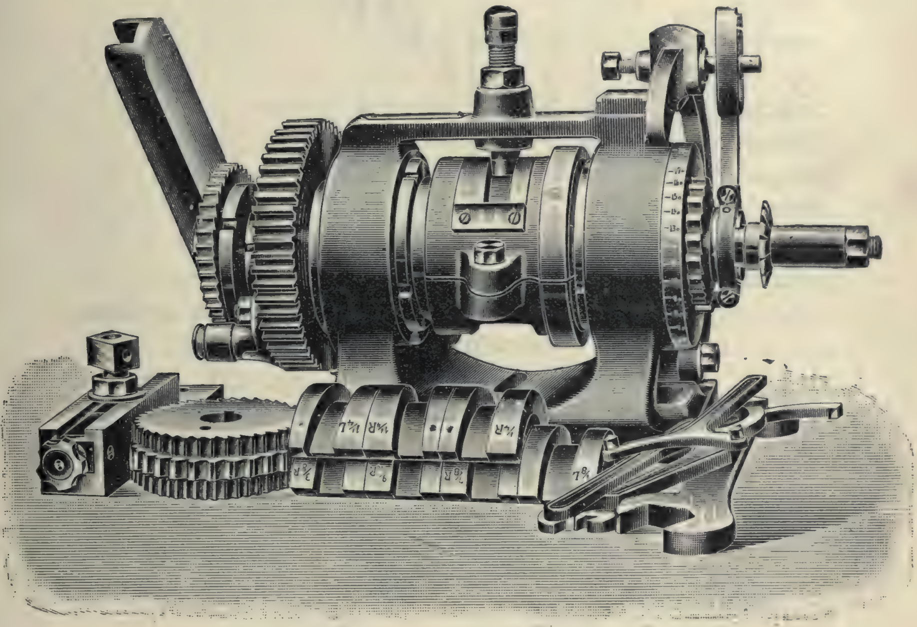


Fig. 496. Backing off attachment.

The attachment is driven by the lathe spindle which carries with it the tail piece which is provided with a slot as seen in the left-hand side of the illustration.

An attachment for the backing off of cutters of comparatively small dimensions is shown in fig. 497. It is not of such solid construction as that shown in fig. 496 and can consequently only be used as an emergency in small factories and workshops. The principle is similar to that of the attachment previously mentioned but it can be mounted between the centres of the lathe without further trouble. The appliance consists of an eccentrical rotating spindle provided with a tail piece (fig. 498).

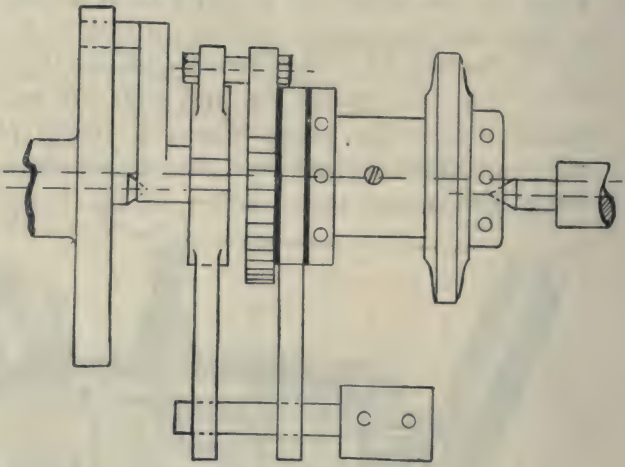


Fig. 497. Backing off attachment.

On this spindle fits a sleeve, (fig. 499), one side of which is turned so as to fit the bore of the cutter *e* which at that part is provided with a key so that the cutter has to move with the sleeve and is clamped by means of the nut *d*.

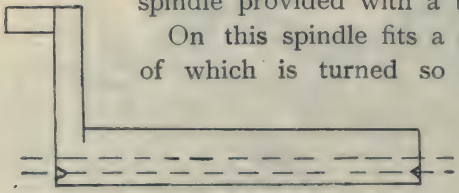


Fig. 498.

A pawl *a* is attached to this sleeve and next to it a friction ring *b* of the form shown in fig. 500. This friction ring is loose on the sleeve but is clamped by the nut *c* by means of fibre washers *i. e.* so that the sleeve can only rotate under friction provided the ring *c* is prevented from rotating with it. In order to prevent it from revolving with the sleeve,

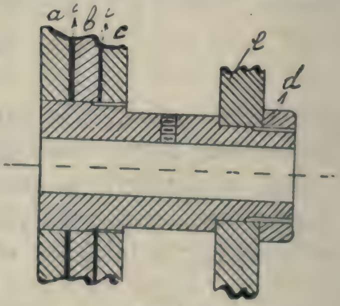


Fig. 499.

this ring, (fig. 500), has a slotted tail piece and a pin which is clamped to some part or other on the carriage of the lathe which prevents its from revolving, (fig. 497). An eccentric, (figs. 501 and 502), is clamped to the spindle, behind the sleeve. One half ring of this eccentric is provided with a tail piece similar to that of the friction ring, and is kept by the same pin which prevents the friction ring from rotating. A pawl is attached to the other ring and this pawl meshes the pawl wheel on the sleeve.

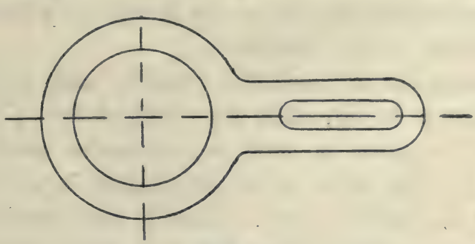


Fig. 500.

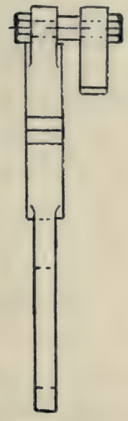


Fig. 501.

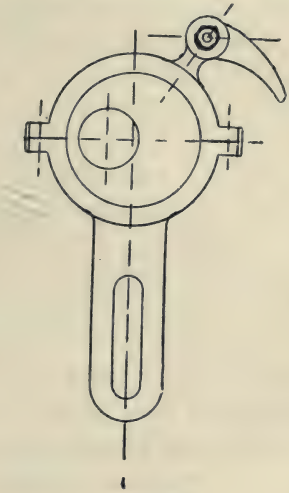


Fig. 502.

The attachment is rather primitive, since another pawl-wheel is required for each different number of teeth of the cutter which has to be backed off whilst the backing off motion derived from the fixed eccentricity of the spindle, (fig. 498), cannot be altered except by using a spindle with another eccentricity and the range is also very limited owing to the diameter of the spindle.

When mounted between the centres and driven by the lathe as shown in fig. 497, the eccentricity of the spindle will cause the cutter to make an eccentire motion, though it will not revolve with it, as the sleeve, is prevented from rotating by the friction ring. During one revolution of the spindle, the eccentric, (figs. 501 and 502), completes one stroke and the pawl moves the cutter one tooth further on. If the cutter has 20 teeth, then during one eccentric movement of the cutter, the latter is moved $^1/_{20}$ th, i. e. the pitch of the tooth.

CHAPTER XV.

The grinding of cutters.

Formerly cutters were not ground. That was when cutter and milling machine were still in their infancy. There were no tools suitable for grinding hardened cutters correctly and no machines for this work. At present it is difficult to think of a cutter the cutting edges of the teeth of which are not ground with the grindingwheel. It was Brown and Sharpe, who introduced simultaneously with the new type of cutter, the "innovation" of the grinding of cutters by means of the grinding wheels which they manufactured, an innovation which speedily proved to be one of the leading factors in the further development of the science of milling. The grinding of the teeth by means of the emery wheel is now not only an indisputable necessity for a new cutter, but the emery wheel and the grinding machine are to-day the great means for keeping the cutter in a perfectly fit state for use. Milling machine and cutter, grinding machine and emery wheel, these four are indissolubly connected; if the milling machine with its cutting tool, the cutter, were deprived of the services of the grinding machine and the emery wheel, the former would cease to be of any practical use. This present chapter will, therefore, treat of the grinding of cutters as a separate branch of milling practice.

In the metal working industry of the present day, the grinding machine with the emery wheel fulfills such important functions that in addition to being regarded as an auxilliary tool for the milling machine, it has also taken its place as a machine type. This chapter will, however, deal exclusively with the cutter grinding machine and then more with a view to its use for the grinding of cutters than to its construction.

The emery wheel, the general name for the artificial grinding wheel is put on the market under names referring more especially to the raw material of which it is composed, such as:—corundum, carborundum, alundum, pyronite, etc.

These raw materials are found as minerals in various parts of the globe, as for instance, South Germany, Spain, Dalmatia, Asia Minor and, as far as corborundum is concerned, more especially in the United States, whilst the island of Naxos supplies emery of an excellent quality, known as Naxos emery, which is crushed by suitable machinery, into fine or coarse grain according to the purpose for which the wheels are to be used. This material is then formed into wheels of the desired form and size either by chemical processes or by being mixed with glue. Wheels for every purpose are manufactured under high pressure from the raw material mixed with other substances determined upon in view of the material to be ground after which the size of the grain and the hardness of the wheel are fixed.

The hardness of the emery wheel and the quality of the raw material determine the proportion of emery and binding material as also the pressure to which the wheel must be subjected during the process of manufacture. In this way fine and coarse grained, hard and soft emery wheels are obtained, whilst in general, although this is not a fast rule, it may be taken for granted that a coarse grained wheel is hard and a fine grained wheel is soft.

As the fine grain gives a much closer wheel than the coarse, it would seem that fine grained wheels are the hardest.

According to the means used for binding the wheels, they are divided into the following classes:—1. Emery wheels made according to the cold process and bound with magnesia-cement. 2. Emery wheels bound with vegetable bond. 3. Emery wheels bound with mineral bond by chemical processes, being subjected to great heat in a furnace.

Wheels bound with magnesia-cement easily absorb moisture, which affects the cement so that such wheels are absolutely useless for wet grinding.

Wheels bound with vegetable bond such as gum, shellac, vegetable oils, gelatine, indiarubber, (this latter being termed the elastic binding), can be used equally as well for dry as for wet grinding.

The emery and the bond are mixed hot in special machines, then pressed into shape under high pressure in hydraulic presses, after which the wheels are burned in a furnace. The more expensive materials used herefor, chiefly indiarubber, as well as the cost of the process and the installation required for their manufacture, make those wheels very much dearer.

The wheels best suited for grinding fine tools such as cutters, knives, etc. are those manufactured by the chemical process and bound with mineral substances. These were originally put on the market under the name of Norton emery wheels and are manufactured in the United States. The principal substances employed in the manufacture of these wheels are alundum and clay, which after being properly mixed, are formed under hydraulic pressure and then exposed to a very great heat. By this method of binding, the wheels acquire their porosity which suits them so eminently for the grinding of cutters, wheras with other kinds of emery wheels the abrasive is completely covered by the bond, thus giving insufficient porosity; in the case of wheels manufactured by the chemical process with mineral bond, the abrasive becomes mingled or vitrified, thus forming one complete whole so that the bond also becomes abrasive. This in conjunction with the easier formation of new grinding and cutting edges owing to their porosity explains the far keener grinding capacity of this class of wheels. Their light weight further ensures greater safety in use.

In addition to these, wheels composed of minerals artificially rendered abrasive are also used in the manufacture of grinding wheels. Amongst these, the carborundum wheels occupy the leading place. Carborundum is derived by a process of melting clay and coke by the heat obtained by electricity, being chiefly manufactured by the Carborundum Co. of Niagara Falls.

The enormous heat required for the manufacture of these wheels renders it only possible to manufacture them where the power required for generating the necessary electric current is exceptionally cheap.

This applies not only to carborundum but also to the various other kinds of wheels placed on the market under various names. Their hardness depends on the mixture added to the natural abrasive, since the expensive artificial material can in general only be regarded as an addition. Owing to their keener cutting edges and greater hardness, these wheels may certainly be reckoned among the best.

For general purposes, ordinary emery from the island of Naxos and the Levant will certainly remain the most advantageous.

Hard objects such as cutters require a soft stone for grinding. Owing to the cutting points of the abrasive quickly becoming dull, they may not be bound too closely.

It is of the utmost importance that during the grinding, that part of the cutter which is being treated, would not become too warm.

With many objects which are being ground, the heat generated is dispersed by a flow of water. Since however, the workman when resharpening cutters, must have the whole of the teeth clearly in view when grinding, the use of a cooling liquid is not possible.

If the cutting edges of a cutter are raised to too high a temperature whilst being ground, the cutter may be regarded as spoiled. Too great an increase of temperature of the parts ground must, therefore, be carefully avoided. In connection herewith the following should be carefully attended to :—

1. Use a soft, sharp wheel.
2. Let the grinding wheel run at the exact speed, not too quickly, but above all, not too slowly.
3. Remove but a small quantity of metal at a time.

Point 1. has already been discussed. The softest wheels are the carborundum, alundum and corundum wheels. In any case, wheels which are manufactured by the chemical process should be employed. The above-mentioned kinds of wheels are the most expensive. Lower price should, however, be no inducement to use wheels less suited for the purpose. The small difference in price will not compensate for the damage caused by soft spots in the cutter tooth as a result of a local increase of temperature caused by the inferior cutting of the wheels.

The surface speed of emery wheels varies from 4000 to 6000 ft. per minute and the number of revolutions must be regulated in accordance with the diameter of the wheel.

In table XXIX the number of revolutions is given for various diameters and surface speeds.

Table XXIX.

Diameter of emery wheel.	No. of revolutions for a surface speed per minute of:—		
	4000 Ft.	5000 Ft.	6000 Ft.
1	15279	19099	22918
2	7636	9549	11459
3	5093	6366	7639
4	3820	4775	5730
5	3056	3820	4584
6	2546	3183	3820
7	2183	2728	3275
8	1910	2387	2865
10	1528	1910	2292
12	1273	1592	1910
14	1091	1364	1637
16	955	1194	1432
18	849	1061	1273
20	764	955	1146
22	694	868	1042
24	637	796	955
26	586	733	879
30	509	637	764
36	424	531	637
42	364	455	546
48	318	397	477
54	283	354	425
80	255	319	383

For the proper carrying out of point 3, the workman must have had the requisite practice and the grinding machine must be so constructed to take a very thin cut from all the teeth in succession.

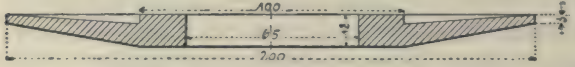


Fig. 503. Hollow sharp edged disc wheel.

The shape of the wheels varies considerably in accordance with the manner of working and the kind of cutter.

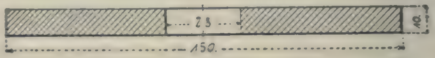


Fig. 504. Cylindrical disc wheel.

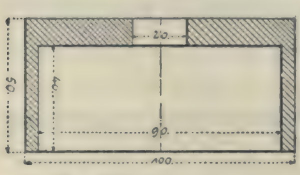


Fig. 505. Cup wheel.

Figs. 503—506 illustrate some of the forms most usually met with.

Those most used are the cylindrical discs shown in fig. 504 and the cup wheel as per fig. 505. Both kinds are employed for grinding shell and end mills of every variety, the discs shown in figs. 503 and 506 being used for deepening the tooth spaces and the grinding of backed off cutters.

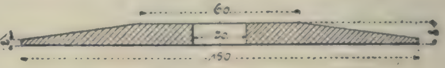


Fig. 506. Sharp edged disc wheel.

Fig. 507 illustrates the grinding of the teeth of an end mill with a disc wheel; fig. 508 shows the same operation being performed with a cup wheel, whilst figs. 509 and 510 illustrate the grinding of shell and

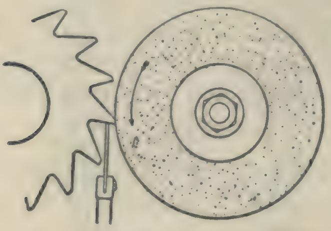


Fig. 507.
Tooth grinding with disc wheel.

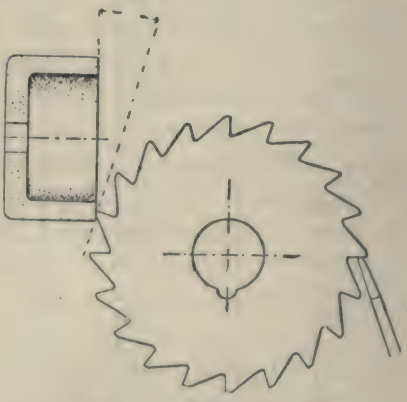


Fig. 508.
Grinding teeth with a cup wheel.

end mills, the two lastnamed operations being carried out by means of the cylindrical disc wheel. Fig. 511 shows the manner in which an emery wheel as per figs. 503 and 506 is used for grinding backed off cutters.

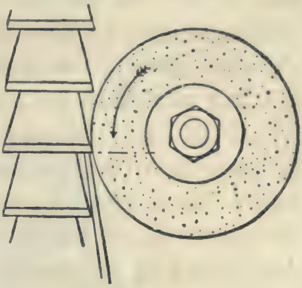


Fig. 509.
Grinding side teeth with a disc wheel.

There is a diversity of opinion as to which kind of wheel is the most preferable for the grinding of the ordinary coarse pitched cutter, the common cylindrical disc as per fig. 504 or the cup wheel as per fig. 505. The manner of working differs considerably in each case. The disc shown in fig. 504 grinds on the circumference, that shown in fig. 505, on the front. The back of the tooth when ground with the cup wheel, shows a grinding line in a longitudinal direction which ensures an accurate and very smooth cut. There is, however, a certain objection connected herewith namely, that the chips will not break, so that a very long chip results which fills up the toothspace and covering the workpiece with chips which can only be removed with difficulty, besides impeding a proper view of the work.

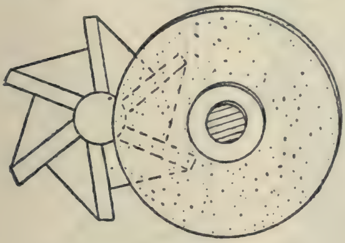


Fig. 510.
Grinding front teeth with a disc wheel.

The emery wheel which works as per fig. 507, produces a tranverse grinding line over the tooth edge which ensures the chips breaking, whilst the adjustment and grinding are rendered much easier. The latter manner of working is far and away the one most generally employed. The only

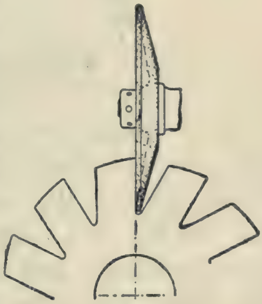


Fig. 511.
Deepening tooth spaces or grinding backed off cutters.

objection to this method is that in cases where the teeth are worn or, in the case of fine teeth, the tooth is not ground flat but concave, as is shown, greatly exaggerated, in fig. 512. It is thus advisable always to choose an emery wheel of as large diameter as possible and to take care that, when the cutter and emery wheel have been so adjusted that the proper clearance is obtained, and the emery wheel does not foul the sharp edge of the tooth above. This also applies in the case of fig. 509.

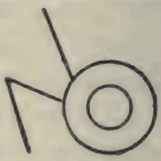


Fig. 512.
Concave ground tooth.

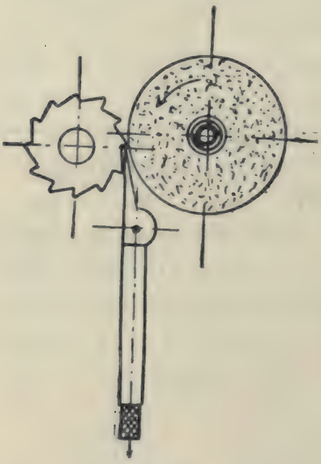


Fig. 513.

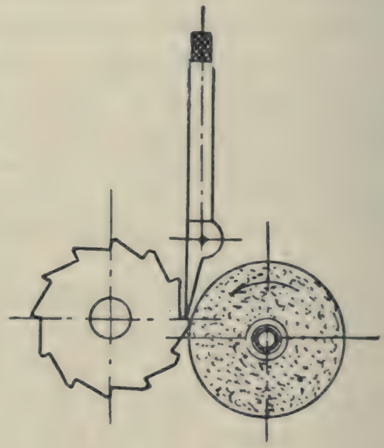


Fig. 514.

Two directions can be imparted to the emery wheel as regards the tooth of the cutter. The emery wheel can rotate *towards* the cut as per fig. 513, or *away from* the cut as per fig. 514. The first-named manner of working has this advantage that the emery wheel forces the tooth against the tooth rest, thus keeping the cutter in a fixed position. The second manner of working is theoretically correct, but is seldom employed in practice.

As has already been stated, this chapter does not purpurt to give anything like a detailed description of the construction of the grinding machine as a type of machine tool, since anything like a complete treatment of the subject would be at least as extensive as that of the milling machine itself. We shall, therefore, content ourselves with the consideration of the milling cutter grinding machine.

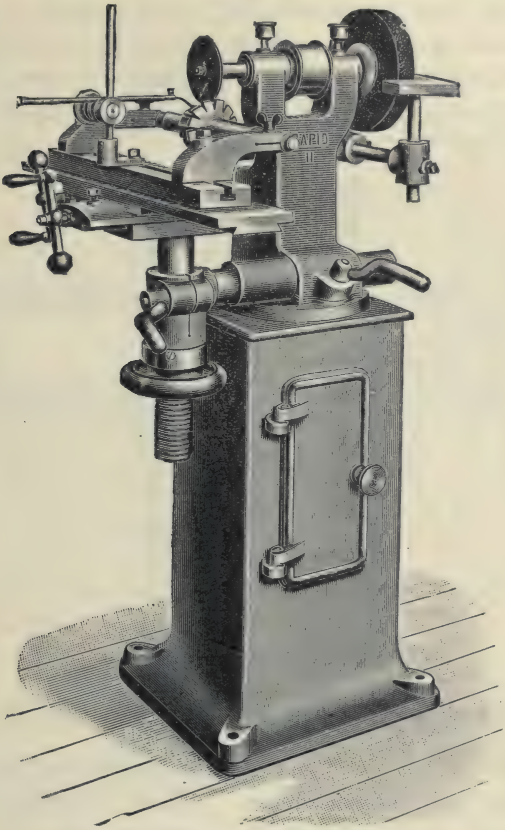


Fig. 515. Milling cutter grinding machine.

The milling cutter grinding machine may be constructed either plain or more universal, though in general construction the various makes differ but little.

Fig. 515, illustrates a milling cutter grinding machine.

A matter of primary importance in a first class grinding machine is the exact bearing of the main spindle in its housings, firstly, on account of the great number of revolutions which this spindle has to make, and secondly, so as to ensure the rotary motion of the emery wheel being free from vibration. Owing to the great number of revolutions and the consequent speed, a liberal lubrication is essential if the spindle is to run easy in its bearings; if however, such a comparatively thin spindle as that of a milling cutter grinding machine which has to make such a great number of revolutions per unit of time, is to run without vibration, it is imperative that it should be very closely housed in the bearings.

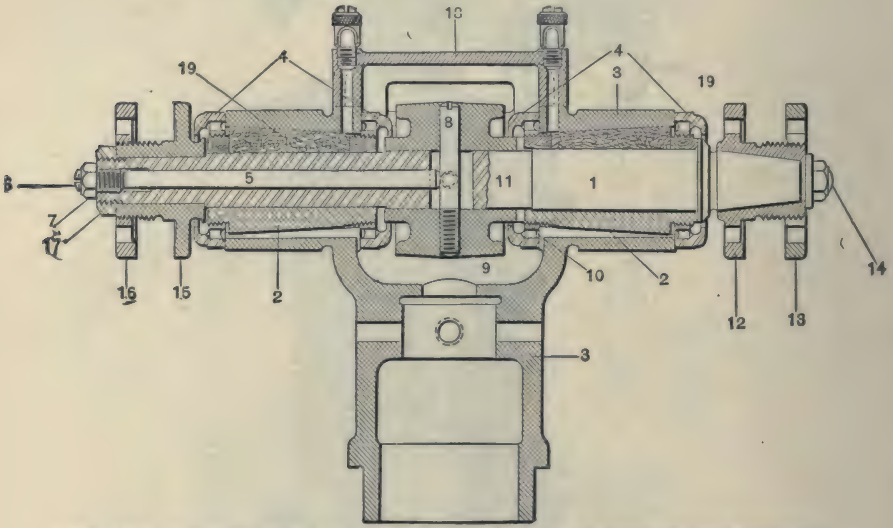


Fig. 516. Sectional view of the main spindle of a milling cutter grinding machine.

Fig. 516 shows the construction of spindle and bearings of a Norton grinding machine. Spindle 1 runs in cylindrical bearings and is hardened and ground according to the Harvey system. The cylindrical bearings 2—2 are of bronze. Externally these bearings are conical and fit in the conical bore of the casting. Wear can be taken up by means of the nuts 4.

The end thrust is taken up by spindle 5 which, in its turn, can be adjusted by screw 6 and presses against the pin 8 in the pulley 9. The hub of this pulley runs against a fibre washer 10. The pressure screw 6 is provided with a nut, whilst pulley 9 is kept in place by means of an adjusting screw 11.

In this way longitudinal movement of the spindle is prevented whilst wear can also be taken up. The top of the bronze bearing has a large opening filled with felt which absorbes the oil supplied by the oil cups.

For internal grinding, two different spindles are used which rotate in an attachment which can be mounted on the grinding table.

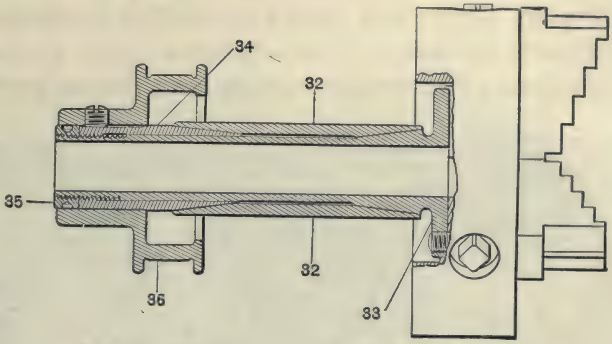


Fig. 517. Spindle and chuck for internal grinding.

Fig. 517 shows a spindle on which a chuck can be mounted, the grinding spindle being illustrated in fig. 518. Spindle 34 runs comparatively slowly and is housed in a bearing which is tapered to both ways.

The spindle shown in fig. 518 has bearings close to the pulley, running on the front side in a long, cast iron bearing. Owing to the limited diameter, abjustable bearings cannot be used in this case. End thrust is provided by a hardened steel nut, whilst the pulley encloses the spindle in a longitudinal direction. This spindle must be able to make 20.000 revolutions per minute and can only be lubricated with kerosene oil.

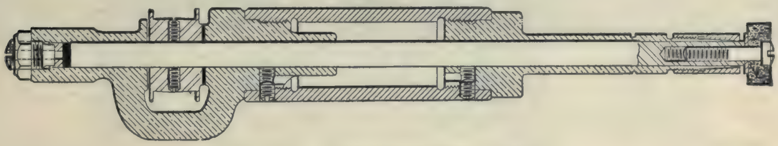


Fig. 518. Internal grinding spindle.

Figs. 519 and 520 illustrate the upper part of a Loewe cutter grinder, arranged in fig. 519 for the grinding of cutters between the centres, and in fig. 520 for the grinding of cutters chucked in the holder 5 by means of their shaft or conical arbor.

The bracket along the column of the machine shown in fig. 519, is vertically adjustable by the hand-wheel 21 (see fig. 520). The centre in bracket 6 can be accurately adjusted by means of the adjusting screw in the bracket in question. The carrier 4 which has a double fork is mounted on centre 2 in bracket 5. On the opposite side of bracket 5 is the indexing apparatus 7 which can be accurately adjusted by the screw in 8.

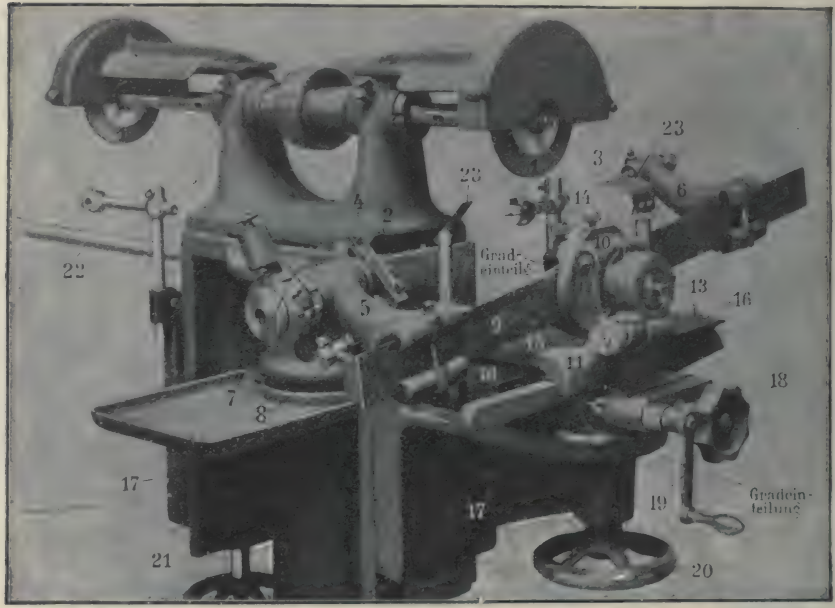


Fig. 519. Cutter grinding machine.

The swiveling head 10 is mounted on the guide. By this means the cutter can be set in each and every position as regards its plane of motion against the grinding wheel. The head itself is held securely by screw 12, the head being secured to the guide surface by screw 14. The head which is graduated in degrees, can be accurately adjusted by screw 11. The crosspiece which can swivel, is clamped by the hand wheel 20.

In fig. 520, the bracket 5 is to be seen in the swiveling head 10 instead of the guide 9. In its chuck, cutters with taper shaft can be placed to permit of end and angular cutters being ground.

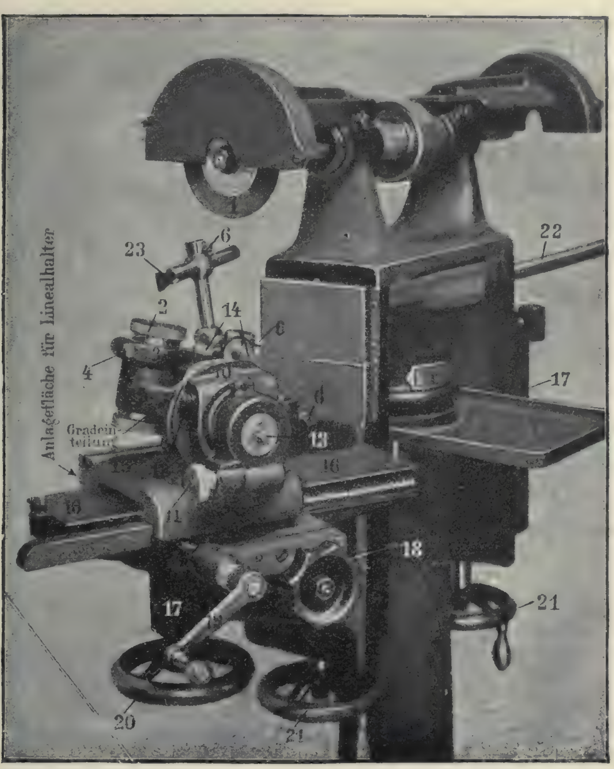


Fig. 520. Cutter grinding machine.

In both illustrations the tooth rests used for placing the cutter in the proper position, are indicated at 23. Many of the illustrations previously given show not only these tooth rests but also the way in which the tooth presses against the rest. It will be seen that this small part of the cutter-grinding machine, performs a most important function. It is employed in a variety of shapes and sizes according to the form and dimensions of the cutter to be ground.

Adjusting the machine.

The cutter to be ground is mounted between the centres, or in the swiveling head 10, (fig. 519). The cross slide must be placed in such a way that for backed off cutters the tooth face is at a proper angle whilst for grinding common teeth, that the tooth when ground has the right angle of clearance.

It will be seen from fig. 108 on page 62 that the angle of clearance may vary between the extreme limits of from 3 to 12 degrees, the smaller angles for hard, the larger for soft metal. The clearance usually varies from 5 to 7 degrees for hard and soft metals. In order to obtain the correct angle, the tooth rest against which the tooth of the cutter is pushed whilst being ground, must be set at the right height. To obtain this, the centres between which the cutter is mounted must be placed a certain distance below the centre line. When using cup-shaped wheels, this distance depends on the diameter of the cutter; when using disc wheels, it depends on the diameter of the grinding wheel.

Tables XXX and XXXI give this distance for cutters and grinding wheels of various diameters for angles of clearance of 5 and 7 degrees.

Table XXX

for setting the tooth rest at the correct height to obtain 5 and 7 degrees clearance for grinding peripheral teeth with a cup wheel.

Diam. of cutter. Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.	Diam. of cutter. Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.
1/4	1/64 —	1/64	3 1/4	9/64	13/64
3/8	1/64	1/64 +	3 1/2	5/32	7/32 —
1/2	1/64 +	1/32	3 3/4	5/32 +	7/32 +
5/8	1/32 —	1/32 +	4	11/64	13/64
3/4	1/32	3/64	4 1/4	13/64 —	1/4
7/8	1/32 +	3/64 +	4 1/2	3/16	17/64
1	3/64	1/16	4 3/4	13/64 +	9/32

Diam. of cutter. Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.	Diam. of cutter. Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.
1 1/8	3/64 +	1/16 +	5	7/32	19/64
1 1/4	1/16 —	5/64	5 1/4	15/64	5/16
1 1/2	1/16	3/32	5 1/2	1/4 —	21/64
1 3/4	5/64	7/64	5 3/4	1/4	11/32
2	3/32 —	1/8	6	17/64	23/64
2 1/4	3/32 +	9/64	6 1/2	9/32	25/64
2 1/2	7/64	5/32	7	5/16	27/64
2 3/4	1/8	11/64	7 1/2	21/64	29/64
3	1/8 +	3/16	8	23/64	31/64

+ after the number indicates that it is fully the given amount,
— " " " " " " " barely " " " .

Set the centres at the same height as the centre of the emery wheel, then set the top of the tooth rest below centering gauge the amount given in the table for each diameter of cutter and clearance (see fig. 521).

Table XXXI

giving the vertical distance below the centre of the emery wheel at which the centres must be set between which the cutter is mounted for 5 and 7 degrees clearance when using disc wheels for grinding peripheral teeth.

Diam. of emerywheel Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.	Diam. of emerywheel Inches.	For a clearance of 5°. Inches.	For a clearance of 7°. Inches.
2	3/32	1/8	4 1/4	3/16	17/64
2 1/4	3/32 +	9/64	4 1/2	13/64	9/32
2 1/2	7/64	5/32	4 3/4	14/64 +	19/64
2 3/4	1/8	11/64	5	7/32	5/16
3	1/8 +	3/16	5 1/4	15/64	21/64
3 1/4	9/64	13/64	5 1/2	15/64 +	11/32
3 1/2	5/32	7/32	5 3/4	1/4	23/64
3 3/4	5/32 +	15/64	6	17/64	3/8
4	11/64	1/4			

Set the centres at the distance given in the table = A (fig. 521), below the centre of the emery wheel.

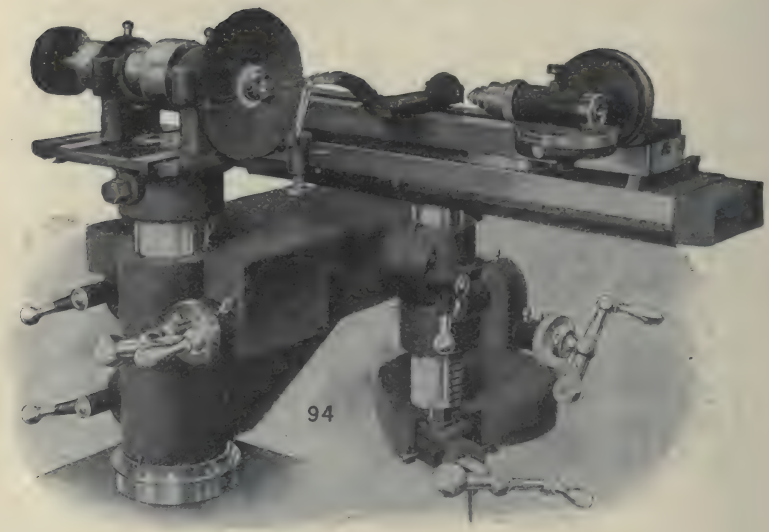


Fig. 521. Adjusting the table to the exact height.

To the equipment of a cutter grinding machine belongs a centering gauge, i. e. a small block which, when placed on the table, indicates the exact height of the centres between which the cutter arbor is placed. This gauge can be seen on the table in fig. 521. In the case of disc wheels the distance A of the tooth rest below the height of the centres is as given in table XXXI for a clearance of 5 and 7 degrees.

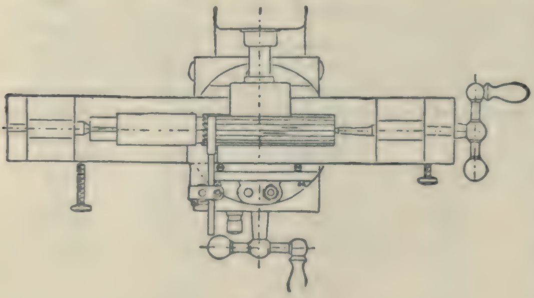


Fig. 522.
Grinding cylindrical cutter with straight teeth.

When grinding the periphery of the teeth with a cup wheel, the centre of the emery wheel is set at the same height as the arbor centres. The tooth rest is then placed the distance A below the centres as indicated in table XXXI.

For grinding a cylindrical cutter with straight teeth, the table travels at right angles to the axis of the main spindle, (fig. 522).

When grinding a conical cutter with straight teeth, the table must traverse a line forming an angle with the axis of the main spindle, the angle being equal to the angle formed by the axis of the cutter with its side, (fig. 523).

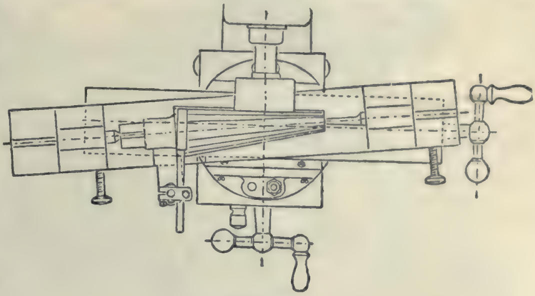


Fig. 523.
Grinding a conical cutter with straight teeth.

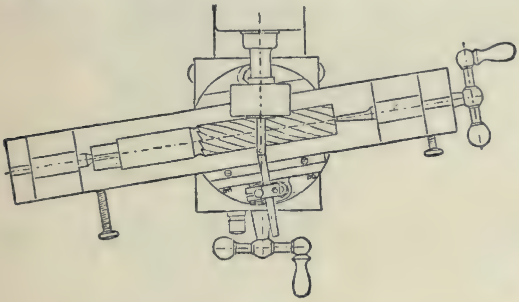


Fig. 524.
Grinding a cylindrical cutter with spiral teeth.

When grinding a cylindrical cutter with spiral teeth, the table must traverse a line forming an angle with the axis of the main spindle, equal to the angle given in table XVI, pag. 148 and 149,(fig.524).

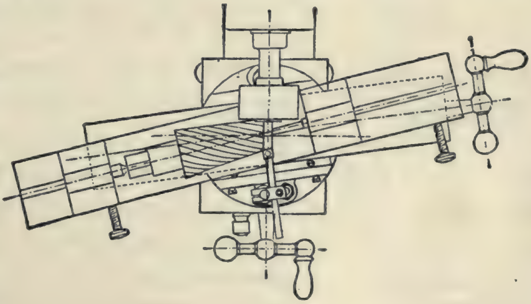


Fig. 525.
Grinding a conical cutter with spiral teeth.

When grinding a conical cutter with spiral teeth, the table must traverse a line forming an angle with a line square on the axis of the main spindle equal to the angle formed by the axis of the cutter and its

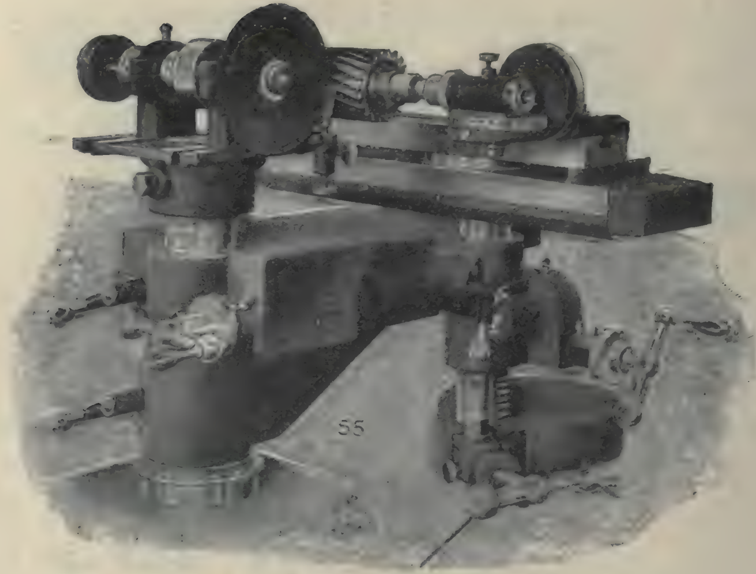


Fig. 526. Sharpening a spiral cutter with a disc wheel.

side increased by the angle given in table XVI, pag. 148 and 149 (fig. 525).

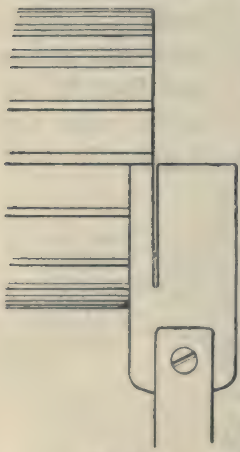


Fig. 527.
Flexible portion of tooth rest.

In the latter case there is a double deviation.

The *angular* travel of the table is not necessary when grinding spiral mills with a disc wheel on the peripheral.

The tooth rest by which the cutter is adjusted to the correct position for grinding, either travels with the cutter or is attached to a fixed point on the machine. In the latter case the tooth of the cutter moves along the tooth rest whether the tooth rest is attached on a fixed part of the machine or on the table. The grinding of cutters with straight teeth can be performed in both ways, but in grinding cutters with spiral teeth, it is necessary to attach the tooth rest to a fixed portion of the machine as the position of the cutter whilst travelling along the emery wheel will only traverse a line equal to the spiral line of the tooth in this way. If at all possible, the tooth rest must be so adjusted as to bear the tooth which is being ground.

Fig. 526 illustrates the grinding of a cylindrical cutter with spiral teeth. The cutter is mounted between the centres. The emery wheel is a disc wheel. When cutting cylindrical cutters with a disc wheel on the peripheral, setting the table at an angle is not necessary. The tooth rest is set at the height of the centres, the centres being the distance below the centre of the emery wheel given in table XXXI. The stops which limit the table travel are so adjusted that the tooth rest cannot pass the tooth of the cutter, but only passes over a portion of it. When the cutter is turned over one tooth, the flexible part of the rest acts as a spring pawl, (fig. 527). When grinding, the cutter must be kept against the tooth rest by hand, which is all the more requisite when

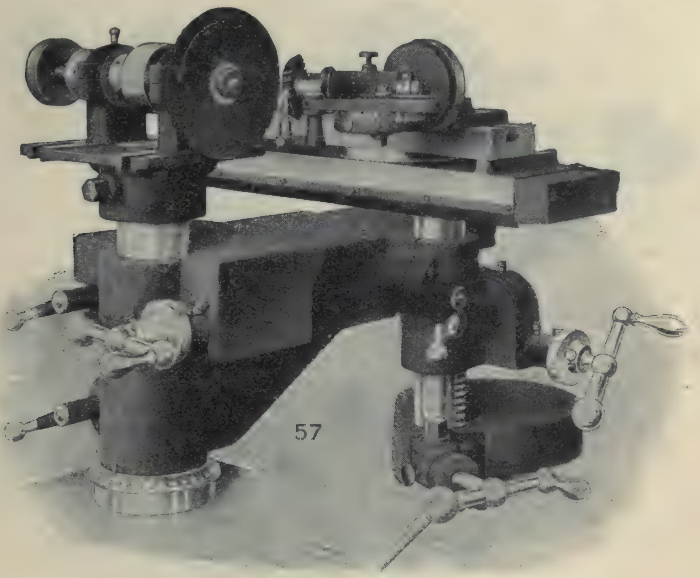


Fig. 528. Sharpening an angular cutter.

the emery wheel rotates as shown in fig. 514 than when it rotates in an opposite direction. As has already been stated, grinding can be done in both ways, that shown in fig. 514 being theoretically correct though a less easy and the least used.

Fig. 528 shows the grinding of a right hand angular cutter with straight teeth. The cutter is held on the end of swiveling head spindle and secured by a bolt through the spindle. The head is then swiveled to the required angle. The tooth rest is set at the centre height of the swiveling head so that the face of the tooth being ground is also at the same height. The table is dropped the required position below the centre of the emery wheel which is necessary according to the diameter of the emery wheel as given in table XXXI and the cutter is kept against the tooth rest by hand. The grinding of a left-hand cutter is identical except that the swiveling head is set to the proper angle on the other side of zero.

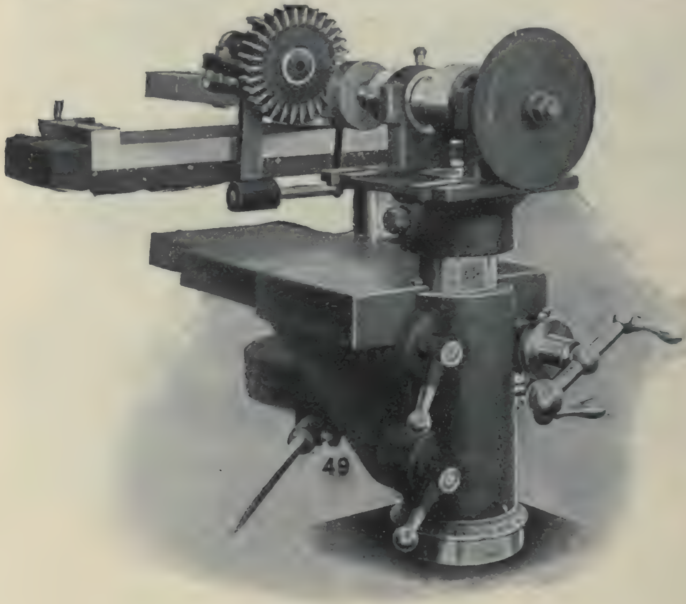


Fig. 529. Sharpening side teeth with cup wheel.

Fig. 529 illustrates the sharpening of the left side teeth of a side milling cutter with a cup wheel. This gives a straight clearance and a stronger cutting edge than the cupped-out clearance obtained by grinding with a disc wheel, the diameter of which is small enough to get between the teeth. The cutter is held on the spindle of the swiveling head and secured by a bolt passing through the spindle. Through the swiveling head which can also swivel in the vertical plane, the cutter is brought sufficiently out of the vertical plane as is necessary to obtain the desired clearance. The knee is $^1/_2$ degree out from the square, being set at $90^1/_2$ degrees, so that the " down " side of the emery wheel will touch the work while the " up " side will clear. The tooth rest is fastened to the swiveling head, its height being so fixed that the face of the tooth being ground is at the same height as the centre of the cutter. For sharpening the right side teeth of a side milling cutter, the setting is exactly the same, except that the knee is now set at $89^1/_2$ degrees

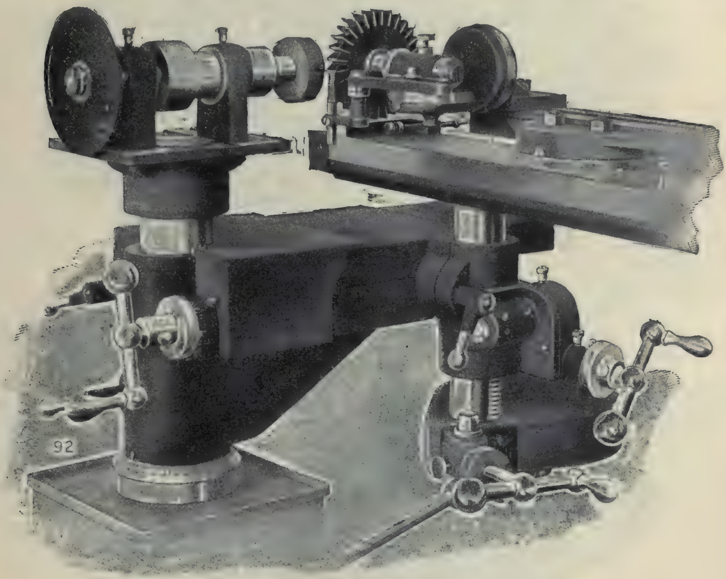


Fig. 530. Sharpening peripheral teeth with cup wheel.

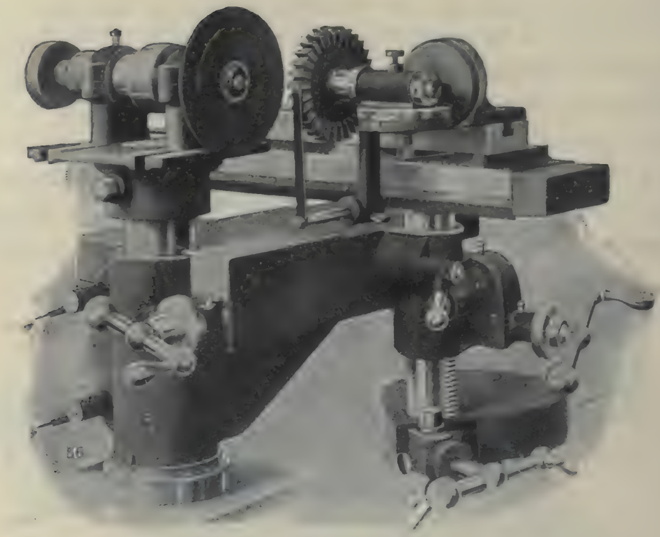


Fig. 531. Sharpening peripheral teeth with disc wheel.

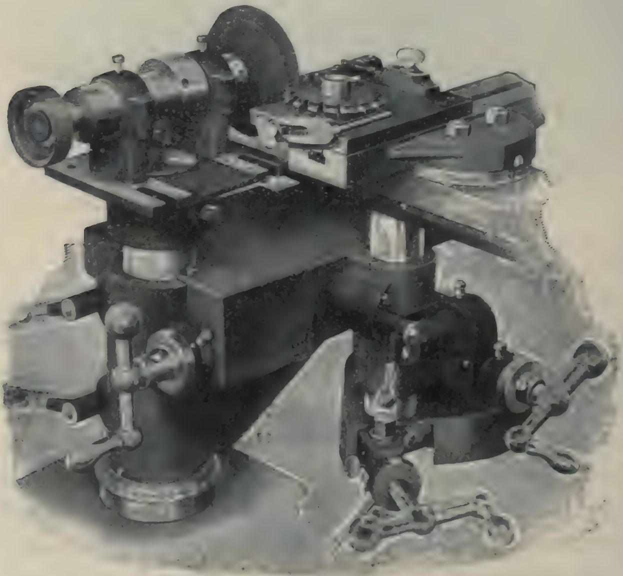


Fig. 532. Sharpening a backed off cutter.

so that the "up" side of the emery wheel will touch the work while the "down" side will clear. When sharpening these teeth, the table must be raised before commencing the operation, until the tooth next to the one being ground clears the top of the emery wheel.

Fig. 530 illustrates sharpening peripheral teeth of a side milling cutter with a cup wheel. The relative positions of the emery wheel and cutter are clear from the illustration. The cutter is now perpendicular in the vertical plane and the centre of the swiveling head is at the same height as the centre of the emery wheel. The top of the tooth rest against which the front of the tooth to be ground bears is now dropped the distance below the centre of the emery wheel indicated in table XXX to obtain the desired clearance. The knee is set at 89½ degrees which brings the "up" side of the wheel in contact with the work. Should the emery wheel strike the tooth next to the one being ground, the table must be raised until this tooth clears the top of the emery wheel.

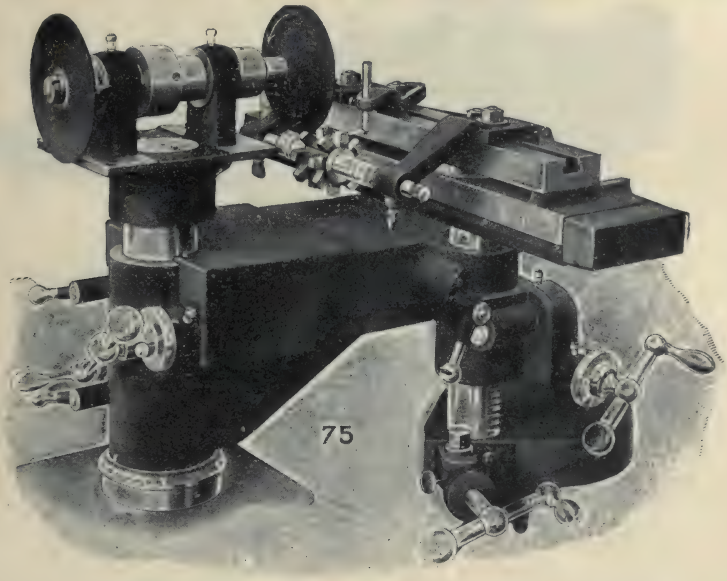


Fig. 533. Sharpening a backed off formed cutter.

Fig. 531 shows the same operation as that in fig. 530, but being carried out with a disc wheel. The position of the knee is however, as regards that in fig. 530, set at 90 degrees. The cutter is perpendicular, the tooth rest is set at the same height as the swiveling head and the centre of the cutter as much below the centre of the emery wheel as is given in table XXXI.

The sharpening of a backed off gear cutter is illustrated in fig. 532. For this purpose a gear cutter grinding attachment is clamped to the table which ensures the faces of the teeth being radial and the same amount being ground off each tooth. The knee is set at a slight angle to the axis of the emery wheel which brings only the edge of the emery wheel in contact with the work.

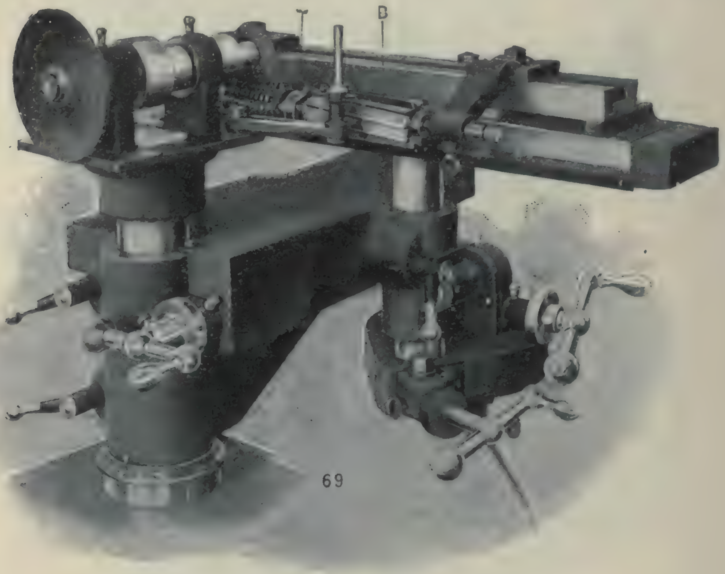


Fig. 534. Sharpening a hob.

Fig. 533 illustrates the sharpening of a backed off formed cutter which is mounted on an arbor and held between special centres. A disc wheel is used. The table is brought towards the column of the machine until the face of the emery wheel is in line with the centres. The tooth rest is then set to the heel of the tooth.

A similar operation to that shown in fig. 533 is illustrated in fig. 534. The cutter which is being ground is a hob with spiral teeth. The hob is sharpered with a disc wheel. The tooth rest is attached to a fixed point on the machine so as to impart to the hob to be ground a movement similar to the spiral line of the teeth; the hob bears against a master form of the cutter mounted on the same arbor but without teeth. The knee is swiveled to the required angle corresponding to the inclination of the spiral.

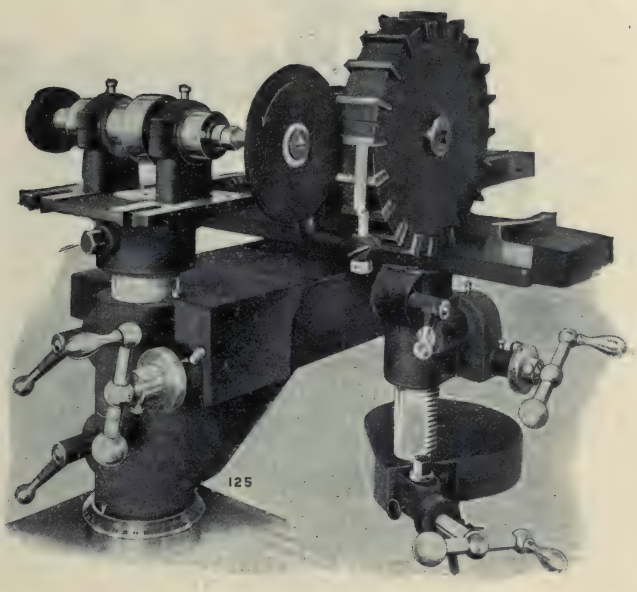


Fig. 535. Sharpening the peripheral teeth of an inserted tooth face mill.

The sharpening of an inserted tooth face mill is illustrated in fig. 535. The mill is mounted on the spindle of the swiveling head which is clamped by a bolt through the spindle. The table is square on the spindle. The tooth rest is attached to the swiveling head, the table being dropped below the centre of the spindle to obtain the correct clearance as given in table XXXI.

The side of the tooth is subsequently sharpened with a cup wheel as illustrated in fig. 530. The cutter is brought out of the perpendicular and inclines to the front so as to obtain the correct clearance. The knee is set at 89½ degrees so that the "up" side of the wheel will touch the work while the "down" side will clear. The tooth rest is attached to the swiveling head and is set at such a height that the tooth to be ground is at the same height as the centre of the cutter.

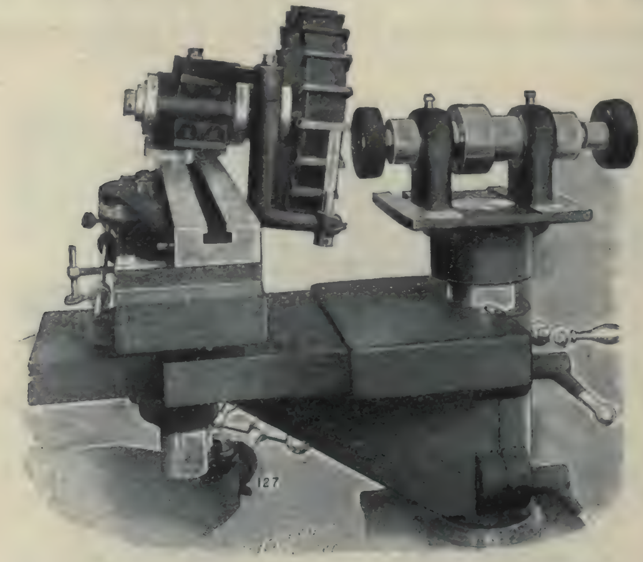


Fig. 536. Sharpening side teeth of an inserted tooth face mill.

The greater number of profile cutters used at the present time are backed off. Backed off cutters are sharpened along the face of the teeth without regard to the form of the cutter (see figs. 532 and 533).

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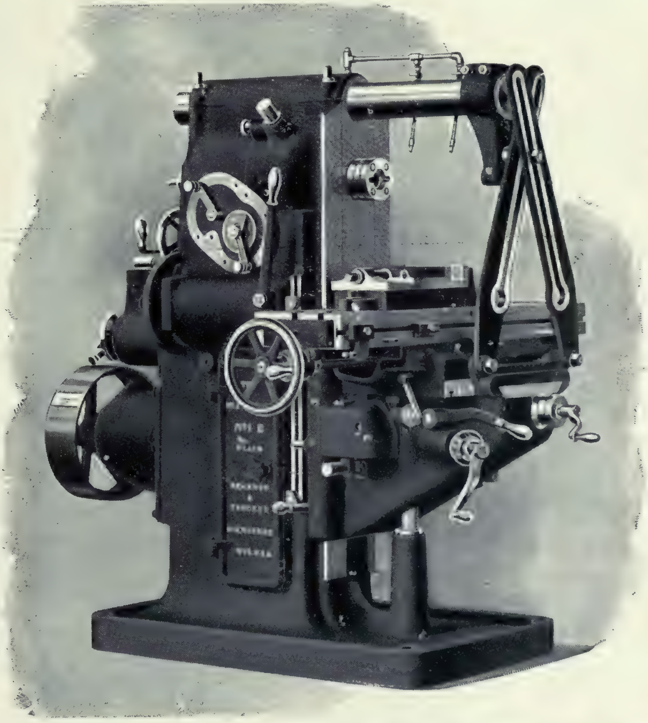

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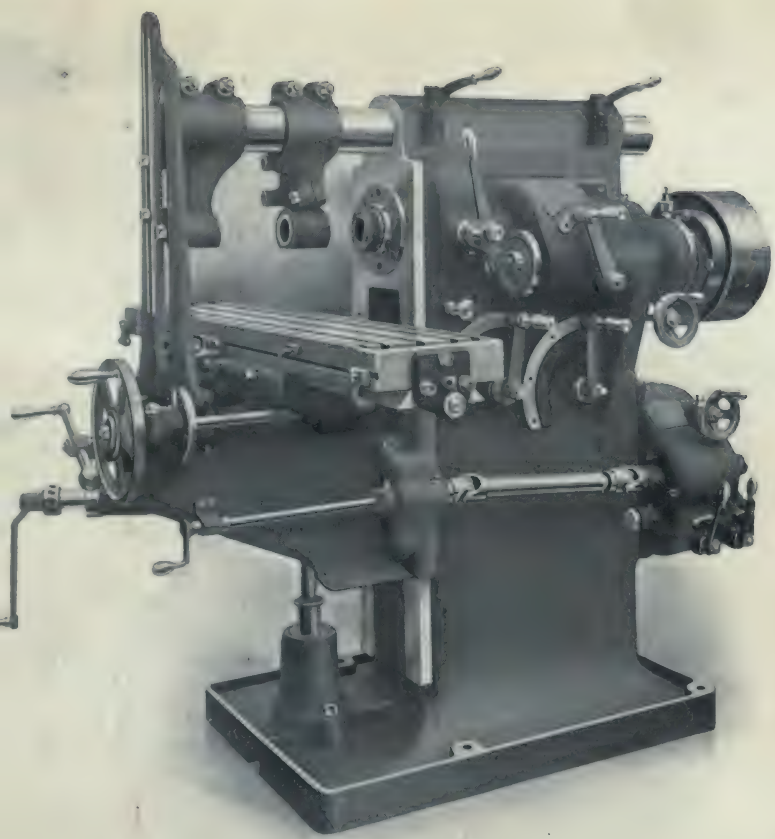

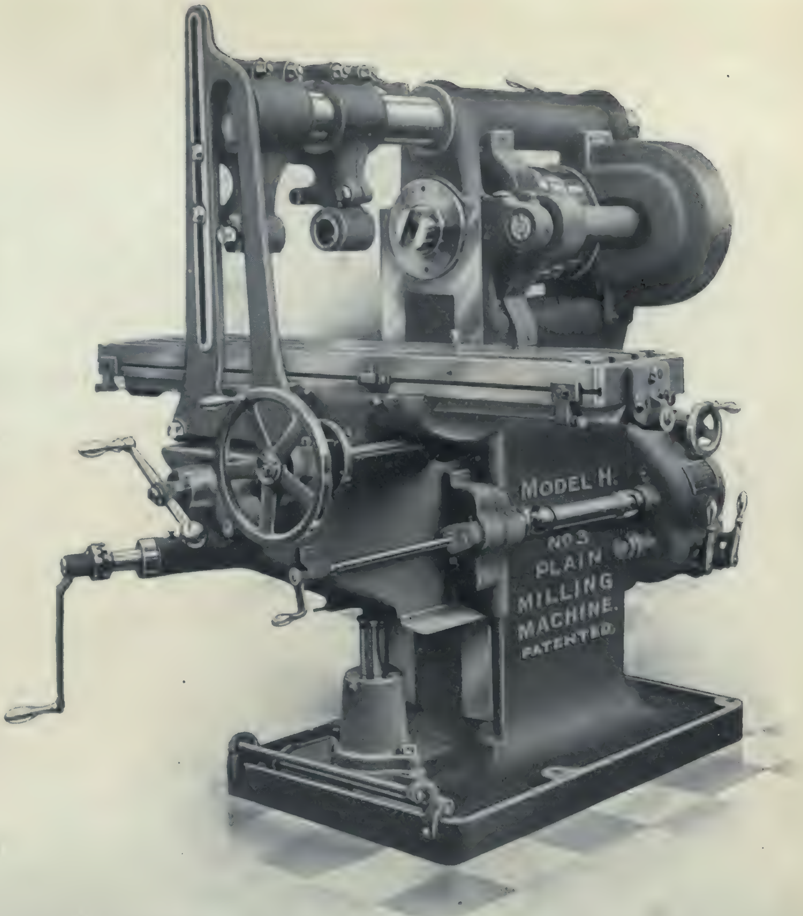

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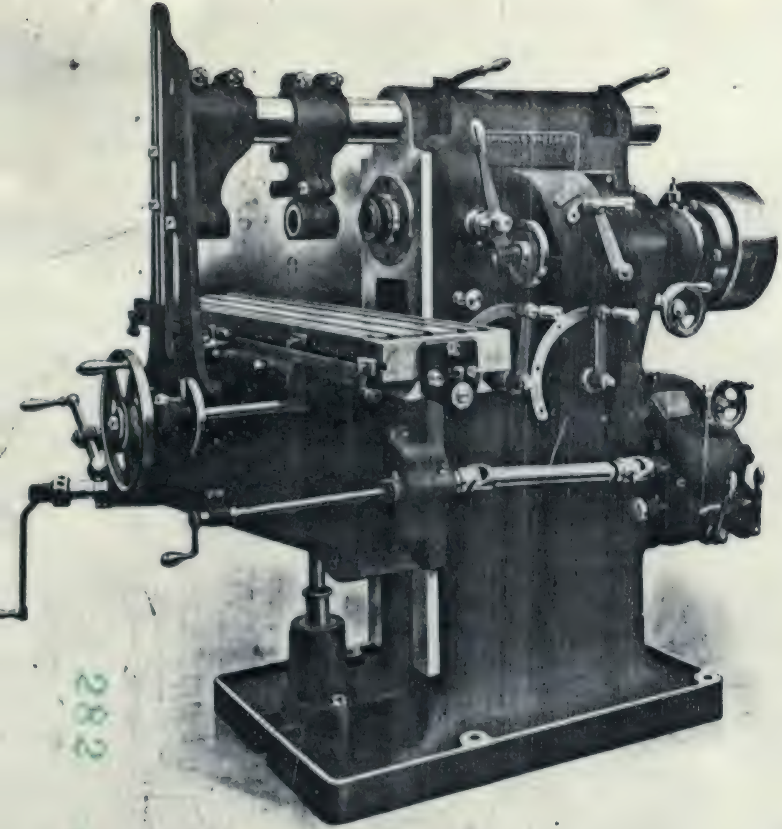

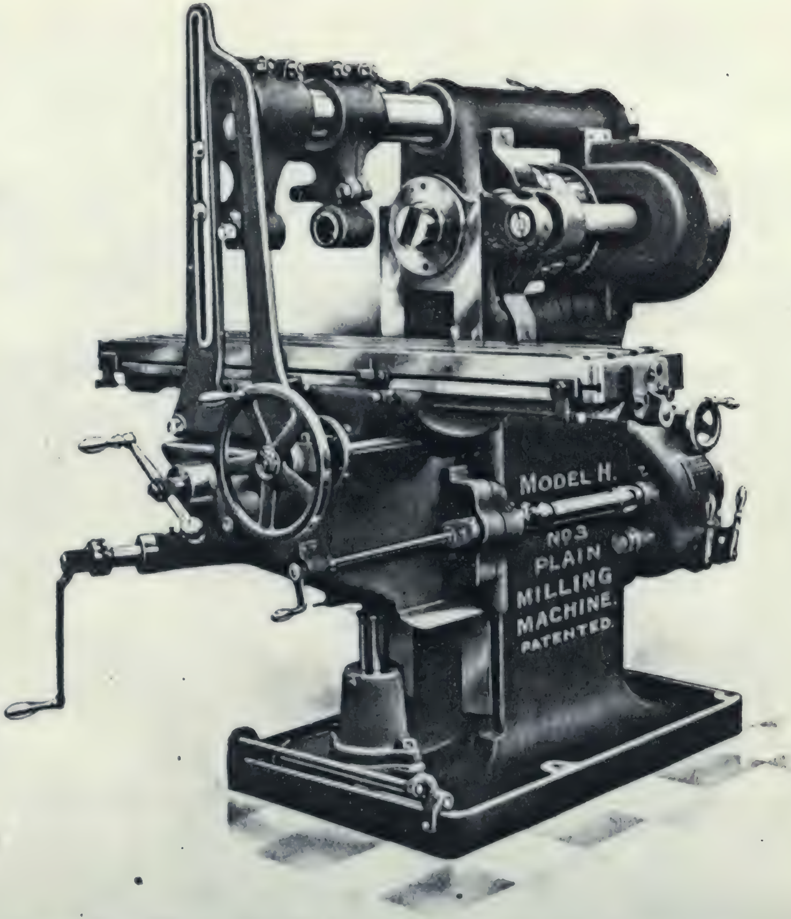

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